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ORIGINAL ARTICLES.

The Geology of Marysville, Victoria.

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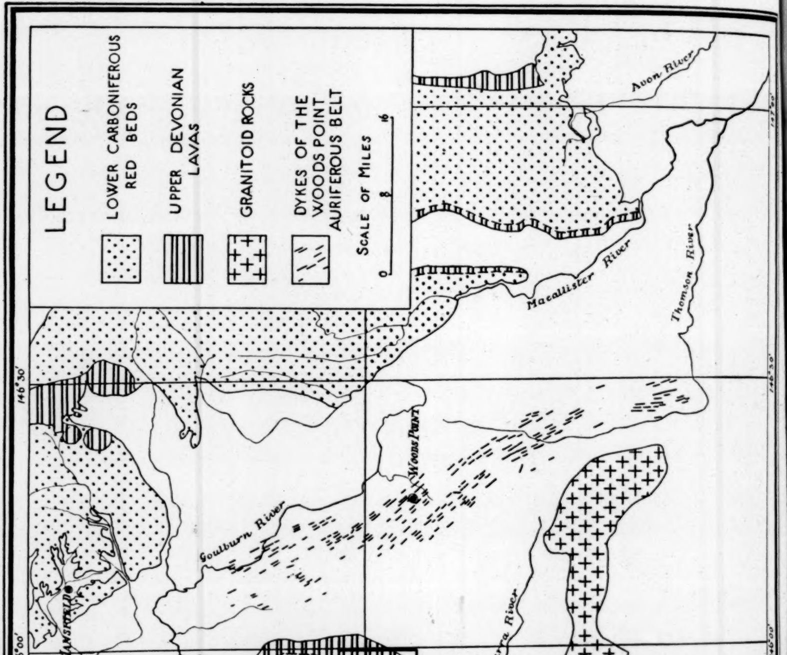
I. Introduction.

(a) *General.*

THE study of the igneous complex of which the Marysville rocks form a part was begun by the writer in 1928, when he first recognized the acid lavas that form the summit of the Blue Hills east of Taggerty, and practically coincide with the edge of the State


LEGEND
LOWER CARBONIFEROUS RED BEDS
UPPER DEVONIAN LAVAS
GRANITOID ROCKS
DYKES OF THE WOODS POINT AURIFEROUS BELT
SCALE OF MILES
0
8
16
Avon River
Macallister River
Thomson River
Goulburn River
WOODS POINT
MANSFIELD
Mt TORBRECK (4320 ft.)
Acid Igneous Rocks
TAGGERTY
Acheron River
BLACK HILLS
Acid Igneous Rocks
MARYSVILLE
NARBETHONG
HEALESVILLE
LILYDALE
Yarra River
Goulburn River
Yarra River
146°30'
146°
145°30'
147°00'
146°30'
146°00'
145°30'
37°30'

Forest Reserve extending eastwards from there among the Cerbereans. Although only a small part of the truly enormous mass of igneous rocks was dealt with at that time, it was clear that interesting stratigraphical and petrological results might be obtained by a more detailed survey, and field work was therefore undertaken at Marysville, some 15 miles south of Taggerty, in 1929.

(*b*) *Location.*

The area described in this paper covers most of the Parish of Steavenson and the eastern edge of the Parish of Granton in the County of Anglesey, as well as the northernmost part of the O'Shannassy Water Reservation in the County of Evelyn. Practically the whole of the Parish of Steavenson is a State Forest Reserve, part of the great forest area of the Cerbereans which, culminating in Mt. Torbreck, constitute a geographical barrier between the Acheron and the Goulburn River valleys. The township of Marysville is distant some 62 miles from Melbourne by road, being situated near the head of the Steavenson River, a tributary of the Acheron, and overshadowed on the east and south by the mountains in which the streams of the Acheron system rise.

The geographical extent of the mountain mass may be judged fairly accurately from the locality map (Fig. 1) for the igneous rocks generally form the high ground. They are bounded by an escarpment which is always steep and may be cliffed, behind which the dissected mass rises within a few miles to elevations of 4,000 feet (Mt. Arnold), 3,600 feet (Mt. Observation), 3,500 feet (Mt. Strickland) [Mt. Bismarck of some maps]), and in the north Mt. Torbreck (4,300 feet).

Although the district is one of strong relief, good exposures are by no means the rule, for encouraged by the high rainfall (over 40 inches average annual) and good soil, vegetation is luxuriant and often impenetrable except with the axe. The typical fern-gully flora produces rank undergrowth, while the eucalypts attain magnificent proportions, up to 365 feet in height, with proportionate girth. The presence of fallen trees such as these in the thick undergrowth, the covering of boulders that rests on even quite steep slopes and the lack of a base map, limit the scope of detailed investigation.

(*c*) *Summary of Previous Work.*

The sum of knowledge regarding the area may be adequately stated to be that acid lavas supposedly related to the central Victorian dacites were known to be present with, probably, some intrusive types. A rough approximation to the delimitation of the boundary of the complex had been gradually attained (see maps by Selwyn 1863, Couchman 1880, Easton 1908, and the later productions of the Geological Survey of Victoria). Langtree (1888) recorded a hornblendic quartz-porphyrite from " near Marysville ", and Skeats (1909) noted the presence of dacite and granodiorite-granite-porphyry 7 miles south of the township. Studies on the geology of contiguous areas have been made by Junner (1915) at Nar-be-thong and Hills (1929) at Taggerty.

II. Physiography

(a) *The Acheron Valley.*

From Nar-be-thong northwards, the valley of the Acheron River has been eroded in the relatively soft Lower Palaeozoic rocks of the " Grundgebirge ", and the headwater and lateral tributaries attack and are incised into the rampart of Upper Devonian lavas which, with their underlying soft tuffs and sediments, form the valley sides. Owing to the rapid undercutting of the Cathedral Beds (near Taggerty and Buxton) and the lavas, the streams early attained a graded condition within the Silurian rocks, even before the valleys had reached maturity, so that subsequent maintenance of grade necessitated the deposition of broad alluvial flats. Attainment of maturity by the valley meant that the period of maximum supply of sediment was passed, so that an era of rapid downcutting supervened, and is still in progress, the streams being incised into their valley plains.

The inter-stream ridges of Silurian rocks in the valley track present the usual symmetrically developed spur systems characteristic of normal submature erosion in an approximately homogeneous series of beds. The stream courses are insequent, most of the hills being determined by minor factors such as slight differences of hardness; thus Mt. Gordon west of Marysville is capped by a sandstone slightly harder than usual.

(b) *The Mountain Region.*

It was at first uncertain whether the level top of the escarpment that bounds the mountain region was to be attributed to peneplanation or to the erosion of a flow dipping away from the valley, but when it was found that even in views at right angles to the escarpment the level top was still to be seen, and further, that small plateau-like remnants such as Mt. Strickland are still sometimes preserved, it seemed clear that the former is the true explanation. This is further supported by the level-topped nature of the Black Hills, which, as they are composed of intrusives and contact metamorphic rocks, cannot be due to the scarping of a bed. Still more convincing is the wonderful view to be obtained from the summit of this range over the country to the east and north, where the tilted blocks of a broken peneplain are clearly to be made out.

III. General Geology.

(a) *Silurian.*

The Lower Palaeozoic sedimentary rocks forming the basement beds at Marysville and in the adjacent country are not highly fossiliferous, and as no detailed work has been done on them, their exact age must remain doubtful, although they are probably, within the area covered by the map and perhaps in the whole Acheron valley from Taggerty to Nar-Be-Thong, of Silurian age. Junner

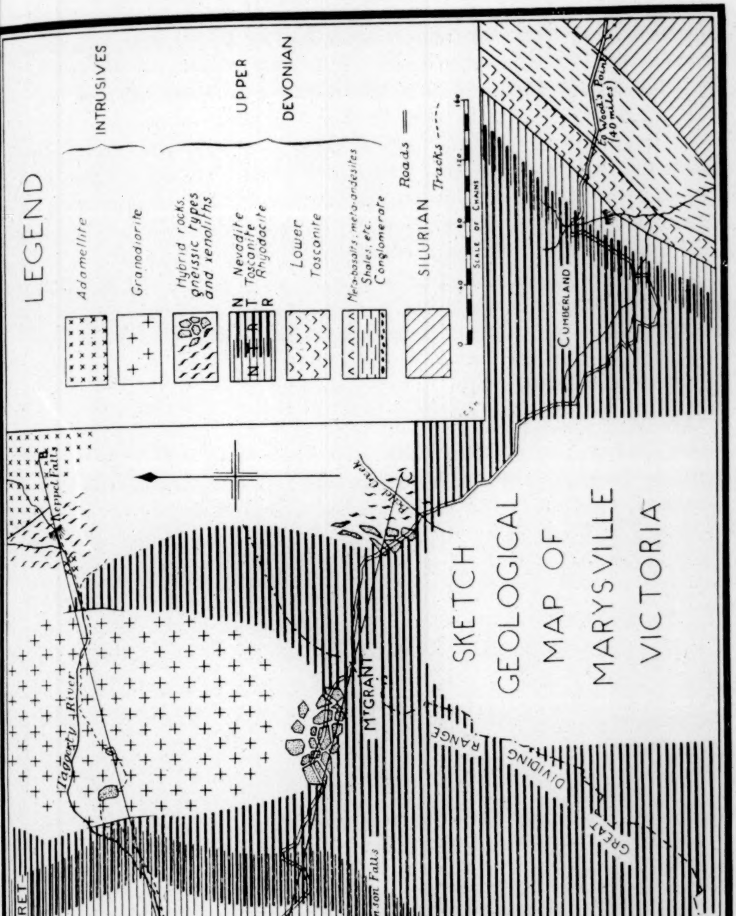

LEGEND
Adamellite
Granodiorite
Hybrid rocks. gneissic types and xenoliths
N Nevadite
T Toscanite
R Rhyodacite
Lower Toscanite
Meta-basalts, meta-andesites
Shales, etc.
Conglomerate
SILURIAN
INTRUSIVES
UPPER DEVONIAN
Roads
Tracks
0 40 80 120 160
SCALE OF CHAINS
SKETCH GEOLOGICAL MAP OF MARYSVILLE VICTORIA
Mt MARGARET
Taggerty River
Keppel Falls
B
Mt GRANT
GREAT DIVIDING RANGE
Steavenson Falls
Keppels Lookout
Talbot Drive
Scree and Alluvium
Rodleys Spur
Steavenson R.
Wilk's Creek
Scree covered slopes
MARYSVILLE
to Buxton (5 miles)
CUMBERLAND
to Wood's Point (40 miles)
Wolfram Mine

FIG. 2.—Geological map of Marysville, Victoria.

(1915) records a determination by Chapman of *Haliserites dechenianus* Goppert from red sandstones near Nar-be-thong, and concludes that the beds are Upper Silurian. The same conclusion was reached by Hills (1929) from the data afforded by a rather meagre fauna from Taggerty.

At Marysville the series consists of sandstones, sometimes current-ripple marked, and shales, in part laminated. At the junction with the Upper Devonian rocks they have suffered silicification accompanied by the introduction of pyrrhotite and pyrite schlieren.

The degree of alteration of the Silurian rocks varies considerably from place to place, and the changes are more intense at Marysville than at Taggerty, where also, the igneous rocks of the Upper Devonian series are fresher.

(*b*) *Upper Devonian.*[1]

Overlying the Silurian rocks unconformably is the Upper Devonian series, comprising mainly great lava flows with subordinate sedimentary rocks of continental origin at the base. It is in the latter that the fossil fishes occur at Taggerty. The land surface upon which these early Upper Devonian sediments were deposited possessed marked relief, so that not only do the basal beds vary rapidly in thickness, and exhibit overlap among themselves while overstepping the Silurian strata, but also the individual formations are of such local occurrence that correlation is difficult. This applies also to the lower (basic and intermediate) lavas, but the great outburst of acid types gave rise to uniform and widespread flows that completely buried all earlier deposits as well as the hills of Silurian rocks that protruded through them.

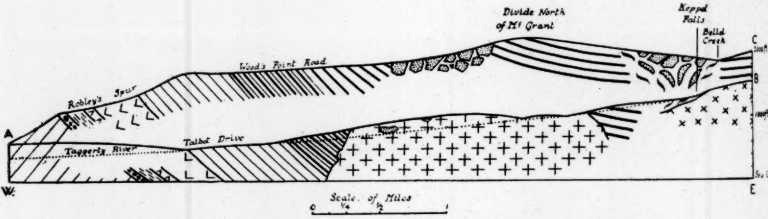


FIG. 3.—Sketch-sections across the western part of the Marysville complex; conventional signs as in Fig. 2. Elevations by anaeroid.

(i) *Basal Conglomerate.*

A thin bed of red conglomerate composed mainly of quartzite pebbles a few inches in diameter marks the base of the series. It is well exposed on the track to Keppel's Lookout and on Robley's Spur.

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[1] For a discussion of the evidence of age and correlation of this series see Hills, 1931.

(ii) *Massive Ashes.*

The thick series of pale grey or buff clastic rocks overlying the basal conglomerate contains much detrital material of igneous origin—quartz, altered felspar, biotite, and zircon—together with numerous grains and prisms of green pleochroic tourmaline, sphene granules and biotite flecks of secondary origin.

It is probable that their equivalents are to be sought in the acid lavas resting on the basal conglomerate in the Blue Hills east of Taggerty and Buxton.

(iii) *Basalt Tuffs.*

At Cumberland, basic lithic tuffs, brilliantly polychromatic, directly overlie the Lower Palaeozoic basement rocks. They contain angular fragments of decomposed basalt, and thus resemble, and are perhaps the stratigraphic equivalents of, the basalt tuffs of Buxton, in which case they are to be regarded as younger than the massive ash beds of Marysville.

(iv) *Meta-basalts and Meta-andesites.*

The first major volcanic episode at Marysville, ushering in the almost unbroken succession of later lavas, was the extrusion of thin flows of fine-grained basalt and porphyritic andesites. These occur at the base of the escarpment, and are often covered over by scree from the acid lavas above, so that their stratigraphical relations are not clear. Both the intermediate and basic rocks have undergone secondary changes, leading to the production of types which may be grouped as meta-basalts and meta-andesites respectively, of propylitic facies (Eskola, 1920). Less altered types occur, however, at Taggerty, and serve to indicate the probable original constitution of the Marysville meta-basites.

Andesitic basalt, Taggerty. [924][1] Anal. No. 1.

The specimen selected for analysis is an andesitic basalt with microporphyritic rectangular plagioclase crystals up to 0·5 mm. long, twinned according to the albite and Carlsbad laws as well as on an axis normal to a macrodome to produce a cruciform arrangement. Though slightly zoned, these approximate to labradorite $Ab_{40}An_{60}$. Pale augites of prismatic habit and often twinned polysynthetically on (100) form glomeroporphyritic clusters in a holocrystalline groundmass of plagioclase laths grading from labradorite to acid andesine $Ab_{65}An_{35}$, small augite prisms, and numerous grains of black iron ore, probably ilmenite. Pseudomorphs of serpentine after (?) olivine are rare. The range of felspar composition as well as the silica content (56·42) indicate the andesitic affinities of the rock (the analysed specimen containing numerous micro-amygdales of secondary silica, however), so that the name andesitic basalt seems appropriate.

This specimen also shows the first stages of propylitization, in the growth of fringes and prismoid individuals of fibrous secondary actinolitic amphibole (pleochroic in shades of pale emerald green and yellow green) round the augite crystals. Plates of this amphibole also develop in the groundmass along with granules of secondary sphene, which also appear marginally to ilmenite crystals, and the plagioclase phenocrysts, especially in their central zones, are sericitized.

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[1] Numbers in brackets refer to specimens registered in the Museum of the Department of Geology, University of Melbourne.

Meta-basalts, Marysville. Anal. No. 2.

The analysed specimen (K.L. 8) is a fine-grained holocrystalline rock (all these basalts are now holocrystalline, though this may not have been their original condition), composed of plates and micro-porphyritic aggregates up to 0·5 mm. long of actinolitic amphibole (pleochroism: X, pale green yellow; Y, yellow green; Z, pale emerald green), black iron-ore grains, apatite prisms, secondary biotite flakes, granules of sphene, and laths of turbid plagioclase. The plagioclase crystals contain numerous dust-like inclusions and usually show no twin lamellae, but a few measurable individuals indicate that oligoclase is common, a feature often shown by melaphyres. A colourless limpid mineral of low double refraction (about ·004), refractive index slightly less than that of balsam, biaxial and positive, with two cleavages, may be a calcisodic rather than a potassic phillipsite. It fills interstices or forms well-defined patches containing numerous needles and plates of actinolitic amphibole and sphene grains.

In one remarkable rock (K.L. 7) these " pools " of (?) phillipsite attain greater prominence and, with zoisite prisms, actinolitic amphibole, penninite, and sphene grains form well-defined aggregates, bounded by a zone extremely rich in secondary sphene grains. These groups are only a few millimetres in dimension, and are arranged in a linear manner, resembling amygdales.

The secondary amphibole sometimes takes the form of asbestos, which fills veinlets and pockets, in one of which occurs the only augite palimpsest recognized in the Marysville meta-basalts or meta-andesites. Limonite patches in these rocks probably represent hydrolysed sulphide specks, crystals of pyrrhotite and (?) pyrite being sometimes observed.

(*b*) *Meta-andesites.* Marysville and Cumberland. Anal. Nos. 3, 4.

The extent of alteration undergone by the intermediate volcanic rocks of Marysville and Cumberland is variable, and even in hand specimen more strongly propylitized types may be recognized, mainly by the presence of numerous specks of yellow sulphides, especially pyrrhotite. Phenocrysts of both plagioclase and uralitic amphibole averaging a few millimetres in diameter are set in a dark grey aphanitic base which from its flinty nature suggests silicification.

One of the analysed specimens (R.*b*) is relatively unaltered, and contains plagioclase phenocrysts up to 5 mm. across, which are beautifully twinned and zoned. The twinning, although mainly according to the Carlsbad, albite, and pericline laws (the latter two polysynthetic), may also be more intricate, cruciform individuals being usual. The zoning of these felspars is also remarkable, being of a very delicate oscillatory character due to alternations of acid and basic shells of only slightly differing composition. In (R.*b*) the variation between the centre and outside of the crystals is not marked, the average composition approximating to $Ab_{50}An_{50}$. Aggregates $\frac{1}{2}$ to 1 mm. across, of pale emerald green to green yellow uralitic amphibole not of fibrous habit, are associated with blebs of pyrrhotite and (?) pyrite, and ilmenite with characteristically developed skeletal leucoxene is prominent. Clouds of secondary biotite are scattered throughout the groundmass, localized as peripheral or internal modifications of amphibole, or enclosed in secondary quartz mosaics with apatite prisms, these assemblages having the appearance of pseudomorphs. Groups of secondary quartz grains, penninite with rare epidote and zircon grains, together with plagioclase plates and laths (basic andesine) complete the rock.

There are many other varieties of meta-andesite, one of which (R. 12) was analysed. In this the phenocrysts are smaller and the groundmass finer-grained and darker. The zoning of the characteristically twinned plagioclase crystals is stronger than in (R. *b*), the zones ranging from a core of labradorite $Ab_{40}An_{60}$ to andesine, but the other constituents are much the same. In other types the amphibole, instead of forming mosaic aggregates, may show groups containing only two or three well-defined individuals, which may even show polysynthetic twin lamellae, but although more strongly coloured than the usual uralitic varieties, there is no doubt that this is not a primary crystallization product of the magma. The secondary biotite in these types has in the aggregate a velvet-brown appearance, individual grains being pleochroic from pale yellow to pale red brown.

In one rock in which the plagioclase phenocrysts have been completely decomposed to masses of very fine-grained saussuritic material, mosaics of clear secondary quartz with intergrown blebs of yellow sulphides are common. It is usual for the alteration of the plagioclase to be confined more or less to the core of the crystal, around which is a frame-like shell of unaltered felspar, which is not noticeably more acid than the core, and is usually andesine.

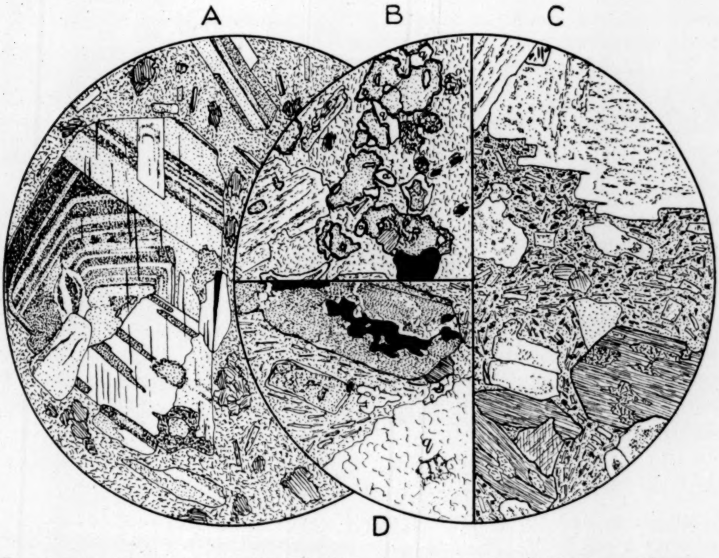

FIG. 4.—A. Meta-andesite, Marysville. × 11. Crossed Nicols. Shows a plagioclase crystal exhibiting oscillatory zoning and complex twinning. B. Meta-andesite, Cumberland. × 11. Ordinary light. Shows pyrite, epidote, apatite (a), and saussuritized plagioclase. C. Meta-andesite, Marysville. × 11. Ordinary light. Shows altered plagioclase, and uralitic amphibole changing in part to biotite. D. Meta-andesite, Marysville. × 11. Ordinary light. Shows aggregates of secondary quartz, sulphides, and biotite replacing amphibole, and altered plagioclase.

Other varieties involve more intensive silicification and sericitization, extensive development of biotite, and specialized parageneses involving apatite, iron ore, sphene, chlorite, silica, and sulphides. The meta-andesites of Cumberland are especially interesting, two main types being recognized, one characterized by the development of much chlorite (penninite), the other by epidote.

In the latter, epidote occurs as large pale yellow-green grains, both replacing plagioclase and as one constituent of secondary aggregates pseudomorphous after ferromagnesian minerals. These pseudomorphs consist of chlorite, sphene, quartz, and black iron ore, the original sub-macroscopic ilmenite crystals producing on alteration a skeletal arrangement of residual iron ore and leucoxene. The plagioclase phenocrysts are acid labradorite $Ab_{45}An_{55}$ twinned in the manner described above for the Marysville meta-andesites, while the groundmass consists of laths of andesine or oligoclase, apatite crystals, and sphene and iron ore grains. Amygdales of quartz and pennine are common.

In the variety characterized by chlorite rather than epidote, pale green slightly pleochroic pennine occurs in association with plagioclase, iron ore, and quartz. There are definite pseudomorphs consisting of chlorite, quartz, iron ore, and sphene grains, and plagioclase encloses, besides chlorite, small epidote grains and flakes of sericite. The other characters are much the same as for the epidote-rich type, except that here we meet for the first time a process that is dominant in some of the more acid rocks, that is analcitization of the plagioclase. An irregular plexus of cracks in the latter forms the locus of change, and the analcite, distinguished by its isotropism, low refractive index, and lack of colour (though it may sometimes be stained with limonite), is very often confined or almost confined to the inner core of the phenocrysts.

(v) *Lower toscanites.* Anal. No. 5.

This group represents the first product of that great extravasation of acid lavas that marked the culmination and close of the period of vulcanicity at Marysville. Although in hand specimens the lavas are often obviously heterogeneous, with patches richer or poorer in phenocrysts or lighter or darker in colour than the average, the group as a whole is remarkably constant, even over a distance of 20 miles.

They are black or grey chert-like aphanites, and contain small broken phenocrysts a few millimetres across of perfectly limpid quartz, and (except where weathered) felspar, both plagioclase and orthoclase, as well as small specks of black biotite. They may be distinguished from the overlying nevadites by the relative sparseness, small size, and limpidity of the phenocrysts, the presence of biotite, and the dark grey-black very fine-grained groundmass.

A specimen (C. 10) from Cumberland contains numerous scattered crystals of quartz, plagioclase, and orthoclase, sheared and twisted biotite, and some relatively large apatite prisms including zircon crystals, also isolated individuals of the latter. The plagioclase is slightly zoned, ranging from andesine-labradorite to andesine, and is twinned according to the Carlsbad, albite, and pericline laws. Orthoclase is pellucid and but rarely exhibits perthite lamellae, which then seem to be restricted to clouded patches, suggesting that the alteration has led to the precipitation of soda felspar from solid solution. Quartz may be embayed, but not to any great extent.

The groundmass varies from a cryptocrystalline paste to coarser granular patches, composed mainly of quartz, felspar (some acid plagioclase), iron ore specks, and chlorite, with sphene grains scattered throughout. Biotite, even in the smallest of flakes, is extremely rare.

Xenolithic fragments are present in every slide of this rock, and even in the widest separated examples fragments of meta-andesite, meta-basalt, and sericitized shale are to be seen. It is very interesting to find that some of these fragments contain sulphide specks that are absent from the surrounding acid lava, and that they show the characteristic epidote-chlorite associations of the Cumberland meta-andesites. Though this might indicate that they were altered before being caught up in the toscanite, a specimen from Taggerty [2246] has clusters of pale yellow epidote in the xenoliths and veinlets of epidote and quartz traversing the toscanite itself.

Pink garnet, altering peripherally and along cracks to biotite, as well as flakes of biotite in the groundmass, are also found in this slide. The latter is never a very important constituent of the toscanites, however, although it may increase a little as in some of the Marysville types.

The groundmass, as well as varying in a more or less continuous manner, is sometimes traversed by veinlets of fine-grained leucocratic nature that seem to be parts of the same rock squeezed off and injected into cracks and gash veins within the lava substance.

The microscopical characters of this group are such as to leave no doubt that mechanical disruptive effects played a large part in their development. The evidence from the shattering of phenocrysts suggests that viscous flow of the lavas may have been an important factor in their emplacement, and it seems likely that many of their features may be explained if this possibility is borne in mind.

A well characterized variant, best described as a member of the lower toscanite group in which the proportion of phenocrysts has been much reduced, is afforded by an aphanitic rock from Cumberland (C. 1). This contains aggregates of pale yellow epidote and chlorite in the groundmass as well as in the meta-andesite xenoliths, but the other constituents do not differ, except in proportions, from the other members of the group. A similar type, except for the absence of epidote, occurs at Marysville, and both seem to be most nearly related to some of the fine-grained veinlets in the porphyritic varieties of the main fragmental toscanite.

(vi) *Crystal tuffs and banded toscanite.*

Between the lower toscanites and the overlying nevadite on Robley's Spur is a narrow band a few feet wide, where soft grey crystal tuffs and pale banded toscanites, with other less important varieties, crop out. The tuffs are soft, and have unevenly disseminated quartz and felspar crystals.

Nevadite-toscanite-rhyodacite suite.

By far the most important, from the point of view of magnitude, of all the lavas, is the great suite which overlies the lower toscanites and ranges from a nevadite at the base by continuous variations in mineral proportions through toscanite to rhyodacite. In the field the nevadite forms the summit of the escarpment at the edge of the mountain region, the formations that have been discussed above cropping out on the lower slopes. It is a hard greyish-white to greyish-black porphyritic rock weathering buff or cream. Phenocrysts of quartz and pink orthoclase averaging 2–3 mm. across are numerous, and increase in numbers towards the top of the flow, where biotite flakes also appear. Continuing upwards in the sequence, the chief variation noticeable in hand specimens is the increase of biotite and white plagioclase crystals, until the toscanite stage is reached. Continuance of these changes leads finally to the production of a rhyodacite of granitoid appearance, rich in gleaming black biotite, white plagioclase, and doubly terminated quartz crystals showing positive and negative rhombohedra, such as are found in all the members of the suite. Although the rhyodacite is the most widespread of all the lavas at the present land surface, covering the upper regions of the mountain mass, its importance in comparison with the underlying flows, whose subsurface extension should be borne in mind, must not be over-estimated. The nevadites and rhyodacites are jointed in a very complex manner, but nearly vertical planes varying little from north–south to east–west respectively are dominant in producing topographic features.

The description and classification of the rocks of this suite involve the problem of the subdivision of what is practically a perfectly continuous series, and is particularly interesting as an illustration of the type of relation that may exist between such acid lavas.

Nevadite.

This is highly porphyritic, with phenocrysts of quartz, microperthitic orthoclase, subordinate acid plagioclase, very rare biotite, and cordierite or its alteration products, set in a groundmass which at the base of the series is microcrystalline with better crystallized patches, and higher up becomes locally microgranular. The quartz crystals have the habit above described, and are usually distinctly biaxial; they include small apatite prisms. The rounded, hypidiomorphic orthoclase is microperthitic, with both plates and irregular blebs of acid plagioclase that merge into each other. It is generally clouded, and it is noticeable that the plagioclase inclusions are more numerous in the more cloudy patches. Simple Carlsbad twins are the rule, and there are minute inclusions of zircon and apatite, sericite being sometimes developed.

The plagioclase crystals (andesine or andesine-oligoclase) are twinned according to the Carlsbad, albite, and pericline laws, and are often broken and shattered, when the pieces may be cemented with more acid felspar of later deposition. Biotite is rare as twisted and crushed crystals wrapping round the other constituents and conforming to the flow lines of the base.

Cordierite is rarely recognizable as such, but is sometimes preserved as remnants showing the characteristic trilling, and thus serves to indicate the origin of the universally present pseudomorphs of the usual decomposition products, " pinite " (various sorts of pale green or brown mica, colourless mica which may show dark pleochroic haloes), and almost isotropic green chlorite. Sheaves of blue tourmaline are a common constituent of these pseudomorphs, but this mineral is also a constituent of the normal groundmass, occurring as radiating or granular aggregates.

As is usual in rhyolites, the groundmass varies greatly in degree of crystallinity, and flow banding is generally marked rather by such variations than by differences in mineral composition, though this may be one factor, especially in the localization of sericite flakes. Though little can be said about the finer parts, coarser schlieren are composed of quartz and potash felspar in the main, the latter sometimes microspherulitic, with subordinate amounts of white mica, and rare biotite flakes. The latter may increase locally, even veinlets being sometimes seen, and yellow-brown slightly pleochroic micaceous material is a constituent, as well as tourmaline. The above description applies to the basal parts of the nevadites, but higher up in the series the proportion of phenocrysts increases and at the same time the groundmass becomes coarser and approaches the microgranular texture of the rhyodacites.

Further, the size of the accessory apatite, tourmaline, and zircon crystals increases, and biotite becomes commoner, muscovite flakes also increasing in size and enclosing groundmass grains poecilitically. With the increase in the number of phenocrysts the amount of broken material also increases and the groundmass becomes filled with small fragments.

Toscanite.

Although the proportions of the orthoclase to plagioclase were not determined accurately (and, indeed, it is almost impossible to do so owing to the fine-grained nature of the groundmass) it is convenient to distinguish those types in which orthoclase and plagioclase are present in sub-equal proportions as " toscanite ", but it must be emphasized that there is no break in the continuity of the lava to correspond with the band marked as toscanite on the map.

There is little point in repeating the description of the minerals already mentioned in connection with the nevadites, but the toscanite of the Wood's Point road especially has certain special features, which may be usefully mentioned. The plagioclase is zoned in an oscillatory manner, and exhibits twinning according to the Carlsbad, albite, and pericline laws. It ranges in composition from a core of labradorite-andesine $Ab_{50}An_{50}$ up to the outer acid shell of oligoclase-albite, which exhibits myrmekite intergrowths as well as another structure of common occurrence in the lavas near the intrusive bodies, that is, lace-like growths round the edge of the crystals, in which grains of the groundmass are enclosed. This structure is shown by phenocrysts of quartz, orthoclase, plagioclase, biotite, and even garnet, and its significance will be discussed later.

The biotite that is beginning to play an important part in the constitution of these rocks is strongly pleochroic from pale yellow to deep red brown (haloes are common round apatite and zircon grains); it is always much bent and twisted, and is often associated with large grains of black iron ore.

Rhyodacite. Anal. No. 6.

Little need be added to the above description to give an idea of the composition of the rhyodacite, for the textures and structures are the same as for the toscanite, but now plagioclase is definitely in excess over orthoclase (which is indeed absent from many slides as a phenocrystic constituent). The crystal size and proportion of accessories has been steadily on the increase, and also garnet is of common occurrence, usually as cracked fragments, but definitely idiomorphic in the case of one rock from the Black's Spur near Nar-be-thong.

Variation of details of structure, texture, degree of alteration and the like is only to be expected within a great series of lavas like the rhyodacites, the mere description of which would be tedious and not of great value. Hence such variations will be treated in a further communication on the petrology of the mass.

Intrusives.

(i) *Granodiorite.* Anal. No. 7.

The main granitoid mass intruded through the lavas is best exposed along Talbot Drive, where the Taggerty River has been deeply incised into the complex. A large intrusion of granodiorite is exposed for a distance of nearly two miles above Horseshoe Bend, but the summit does not quite attain to the level of the Wood's Point road. It is a non-porphyritic rock with white felspars and small blebs of biotite, and carries large xenolithic blocks of various kinds.

Under the microscope the analysed specimen, M. 3, is seen to consist of quartz, plagioclase, subordinate orthoclase, and single biotite crystals, together with aggregates of the latter mineral in association with badly formed actinolitic amphibole, ilmenite, apatite, zircon, and small sillimanite rods in parallel groups within clear quartz.

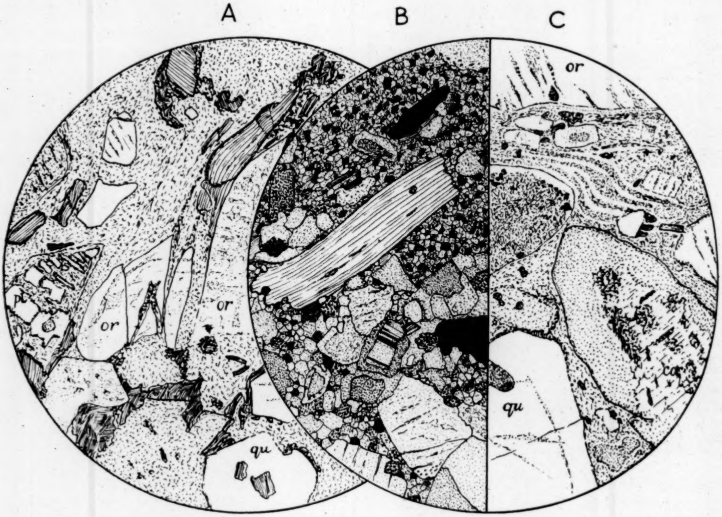

FIG. 5.—A. Rhyodacite, Tommy's Bond, near Marysville. × 11. Ordinary light. Shows effects of presolidification shear on phenocrysts of orthoclase (or), biotite, plagioclase (pl), and quartz (qu). B. Meta-toscanite, Marysville. × 11. Crossed Nicols. Shows recrystallized groundmass and regrown fragments of phenocrysts of plagioclase, orthoclase, quartz, and biotite. C. Nevadite, Taggerty. × 11. Ordinary light. Phenocrysts of perthitic orthoclase (or), quartz (qu), altered plagioclase, and cordierite (cor) are set in a cryptocrystalline to microcrystalline groundmass showing flow banding.

In the body of the rock the quartz is of plutonic habit, with strings of bubbles, and is interstitial, carrying small inclusions of muscovite. That it has been subjected to stress is indicated by waved and mosaic extinction. The orthoclase is microperthitic, the intergrown plagioclase being either in the form of plates or blebs, which seem to grade into each other.

The plagioclase is distinctive in that it is twinned according to the Carlsbad, albite, and pericline laws, as well as being strongly zoned, with an internal core of andesine-labradorite showing oscillatory zoning, surrounded by a jacket of acid oligoclase or oligoclase-andesine grading to albite and exhibiting normal waved extinction. The core may be rounded and separated from the outer coat by a zone of decomposition products, and is often sericitized. All the plagioclases are not of this type, and fresh andesine grading into oligoclase and often showing very well the change of sign of extinction at $Ab_{80}An_{20}$ are also seen, as well as certain interesting groups of small jacketed plagioclase crystals.

So much of the biotite is associated with the melanocratic aggregates that it is difficult to be sure whether all is not thus associated, and whether isolated crystals are not merely sections of the edge of such groups. The colour is deep brown, and the pleochroism from X : light red brown, to Y, Z : deep brown, pleochroic haloes round zircon and apatite being very common. The groups in which this mineral forms such a conspicuous component are about ¼ in. across, and are composed of pale actinolitic amphibole, black iron ore, apatite crystals up to 0·8 mm. long, zircon crystals up to 0·5 mm. long, clear quartz containing small parallel sillimanite rods, and much biotite rich in pleochroic haloes. When the biotite is chloritized, large sphene grains are associated ; the apatite crystals often have a central core of (?) carbonaceous matter.

Pyrite is of rare occurrence in the granodiorite, and a few epidote grains are also to be observed at times in altered plagioclase. It is interesting to note that myrmekite is of general occurrence ; but the less intimate details of mineralogical relationships will be left over for further discussion.

(ii) *Adamellite.*

At Keppel Falls a pink porphyritic adamellite occurs in contact with the migmatoidal rocks. It is rather finer-grained than the granodiorite, and contains orthoclase crystals up to an inch long, usually with a central core divided off from the outer part by a zone of small biotite grains. Small melanocratic xenoliths containing pink garnet and biotite are common. The extent of the outcrop of this rock was not investigated, but it certainly extends for some distance outside the area mapped.

It is composed of quartz, orthoclase, plagioclase, biotite, cordierite, and its alteration products, together with smaller amounts of pink garnet, sillimanite, apatite, zircon, and black iron ore.

Quartz shows strain polarization, and the plagioclase presents almost exactly the same features as in the granodiorites, that is, an internal core of basic andesine plastered with a jacket of oligoclase-andesine to oligoclase-albite, the core being often altered, and exhibiting oscillatory zoning, as well as albite, pericline, and Carlsbad twins. Orthoclase is clouded, and although it carries veinlets of acid plagioclase, typical platy perthite is not developed. It may be sericitized along cracks, and include quartz, plagioclase, biotite, apatite, and zircon. Biotite is pleochroic from X : pale yellow brown to Y, Z : dark red brown, and shows numerous pleochroic haloes. It is in part chloritized.

In certain bands pale cream-coloured cordierite and its alteration products pinite or yellow (?) serpentine, are extremely common, and xenoliths containing pink garnet, cordierite, biotite, zircon, quartz, apatite, sillimanite, and iron ores are found to be locally important. Myrmekite and other intergrowths are particularly well developed in these adamellites.

(iii) *Aplites.* Anal. No. 12.

Small aplite veins are found at various places along Talbot Drive, as at Keppel Falls, Phantom Falls track, and near the western contact of the granodiorite.

(iv) *Hybrid Rocks.*

At Keppel Falls and Bellel there are hybrid rocks which unfortunately could not be studied in great detail in the field, owing to the lack of good exposures. They range from eruptive breccias to gneisses, and are composed in the main of acid porphyritic rocks veining or filled with xenoliths of meta-andesite (chiefly). It is clear that they form a well-defined group with characteristic field and microscopical relations, and the solution of the problem of their genesis should have an important bearing on the structure of the complex as a whole.

In contact with the adamellite at Keppel Falls is a gneissic granodiorite-porphyrite banded parallel to the contact with layers rich in biotite. It is composed essentially of quartz, plagioclase (acid labradorite-andesine), orthoclase with sub-rectangular inclusions of zoned andesine, biotite (X pale yellow brown, Y, Z deep brown) all of which occur as phenocrysts a few millimetres across, and as constituents of the groundmass. Apatite and zircon are the chief accessories.

For the description of the hybrid rocks the most convenient starting point is that type in which the included fragments are sharply defined, and presumably still retain some of their original features. The dark fragments are composed of plagioclase phenocrysts, aggregates of amphibole and secondary biotite, black iron ore, and quartz grains.

The plagioclase phenocrysts are not very strongly zoned, but exhibit oscillatory variation. They are twinned according to the albite and Carlsbad laws, more rarely according to the pericline, and some form of alteration, either sericitization or development of cloudiness due to the presence of minute indeterminate specks, is usual. Secondary pleochroic hornblende (X : light yellow green ; Y : emerald green ; Z : blue green) occurs in groups of badly formed crystals reminiscent of the uralitic amphibole of the meta-andesites of Keppel's Lookout and Robley's Spur. It is rather more strongly birefringent and pleochroic, however, and may be slightly zoned, the outer parts being a little bluer, clouds of magnetite grains centrally situated suggesting derivation from a more ferruginous pyroxene. Biotite fringes ilmenite grains, and is aggregated peripherally to the amphibole, suggesting derivation from the latter. It is also a constituent of the groundmass, which contains quartz, plagioclase, iron ore, and apatite grains as well. Much of the quartz is localized in swarms of biotite, or between biotite aggregates and amphibole, indicating that it may be connected genetically with these minerals. A rare constituent is blue tourmaline in small prisms.

There can be little doubt that this inclusion is a meta-andesite, and in other fragments the groundmass still shows well-defined plagioclase laths, so that there is no question of the original nature of the rock.

The interstitial acid rock in this case has phenocrysts of quartz, plagioclase, biotite, and subordinate orthoclase set in a fine-grained granular groundmass of the same minerals. Its abnormal nature is shown, however, by the alteration of the biotite, which is chloritized and contains large sphene grains, the presence of large brown tourmaline crystals, and pale yellow epidote crystals and aggregates. It is noticeable that the biotite of the xenoliths is not chloritized, even though that of the surrounding rock may be completely changed.

The preponderating hybrid type found below Keppel Falls is a gneissic rock weathering in a platy manner and containing numerous aligned inclusions, both melanocratic and leucocratic. The former are believed to be meta-andesites in process of granitization, and are worthy of detailed description.

A xenolith consisting of uralite and plagioclase phenocrysts with a few rather large quartz grains set in a fine-grained groundmass of andesine laths, amphibole, iron ore, and secondary biotite grains, exhibits a series of changes as the periphery of the fragment is approached. Rather suddenly small biotite prisms become numerous in the groundmass, and crowd round the amphibole, entirely replacing the smaller particles. The plagioclase laths lose much of their distinctness and become granular, and quartz increases in amount. Nearer the periphery the grain-size of all the constituents increases, the granularity of the groundmass becomes more and more pronounced, and the replacement of amphibole by biotite more complete. There is a general alignment of biotite flakes parallel to the edge of the fragment, from which pieces become removed and incorporated in the surrounding magma. The indigenous felspar of the latter is twinned in fine lamellae according to the albite law, with also simple Carlsbad twins and pericline lamellae. It is only very slightly zoned, and approximates in composition to andesine $Ab_{60}An_{40}$. On the other hand, small plagioclases with a more or less rectangular core of andesine-labradorite or labradorite, much altered, and coated with a sharply defined jacket of acid andesine, exactly resemble the felspar of the outer granitized zone of the meta-andesite fragments, and usually occur in their new habitat in small groups.

In the complex belt near Bellel, where meta-andesites form one of the constituents of eruptive breccias which probably are part of the zone just described, the shattered blocks are somewhat larger, but show very similar microscopic characters. Analcitization of the felspars is very common, however, and in the smaller particles the replacement of amphibole by biotite has gone on to completion.

The leucocratic lenticles in the hybrid rocks of Keppel Falls may either consist entirely of quartz, or of granitoid aggregates of quartz crystals polarizing in mosaic patterns together with somewhat crushed plagioclase (andesine $Ab_{55}An_{45}$ to $Ab_{65}An_{35}$ plastered with acid oligoclase $Ab_{90}An_{10}$) exhibiting fine albite lamellae as well as pericline and Carlsbad twins. Large strongly pleochroic tourmaline crystals (ϵ colourless, ω blue; or ϵ yellow, ω dark green) are in close association with the lenticles, and chloritized biotite, grains of quartz, potash felspar, zircon, and apatite constitute the subordinate interstitial material.

Along the Wood's Point road above Robley's Spur is a zone about half a mile in width which consists of blocks of sedimentary rocks in various stages of alteration, veined in a complex manner by what, in the field, appeared to be acid porphyritic rocks. It seems most probable that these sediments represent a block of the basement rocks torn off and caught up in the lavas during their eruption, or during the movement of the magma preliminary to that event.

Diopside-bearing xenoliths in the granodiorite.

There remain to be considered the major xenoliths in the granodiorite. Firstly, there are some remarkable rocks forming apparently irregular inclusions some scores of yards across, that seem to merit treatment here rather than elsewhere, though similar types in America have been regarded as aplites. Variation within these masses is great, the most peculiar type being compact and light coloured with small crystals of pale diopside and secondary tremolitic amphibole set in a granular mass of felspars and quartz.

Under the microscope pale diopside is seen to be giving rise to secondary tremolitic amphibole, and there are fairly large crystals of sphene, apatite, and zircon prisms. Secondary sphene develops round ilmenite, and rare colourless zoisite and pale green penninite arise in the groundmass or after biotite. The felspars are very interesting. Many of them are cross-hatched, but the double refraction is definitely higher than microcline, and as the chemical analysis of the rock shows 6·88 per cent Na_2O and only 0·89 per cent K_2O it is practically certain that they are related to the anorthoclases, and represent what Alling (1921, 1923) classes as "analbite". These types of felspar are intimately related to antiperthite in the Marysville rocks, for both types may be developed within the one individual crystal, antiperthite at one end, and cross-hatched analbite at the other—again in favour of the conclusion that the latter is a sodic type. There are also andesine phenocrysts coated with acid oligoclase or albite, in which the line of demarcation between the inner and outer parts is very uneven. Quartz is relatively subordinate, and shows, along with the other minerals, the effects of slight post-solidification stress.

The main mass of which the above is a variant is, however, not so peculiar. Orthoclase veined with albite increases in amount as the sodic types of felspar decrease, and the alteration of the diopside may have not even commenced. Large sphene, zircon, and apatite crystals, chloritized biotite containing secondary sphene, and jacketed plagioclase complete the assemblage.

TABLE I.

	1.	2.	3.	4.	5.	6.
SiO_2 .	56·42	48·17	61·65	54·97	69·86	67·17
Al_2O_3 .	13·92	14·54	16·45	14·30	14·82	14·86
Fe_2O_3 .	2·59	1·97	0·37	0·95	1·47	0·43
FeO .	5·12	7·58	4·89	7·11	1·33	3·87
MgO .	6·17	7·29	2·36	5·13	1·18	1·61
CaO .	8·37	8·60	5·88	8·47	1·88	2·84
Na_2O .	2·75	2·86	3·26	2·70	2·57	2·48
K_2O .	2·13	2·17	2·15	2·08	4·24	3·77
H_2O + .	1·10	1·94	1·00	1·23	2·00	0·90
H_2O − .	0·29	0·68	0·14	0·15	0·44	0·12
CO_2 .	0·03	tr.	0·09	tr.	0·04	0·20
TiO_2 .	1·06	2·77	0·80	2·96	0·28	0·87
P_2O_5 .	0·24	1·41	0·55	0·90	0·51	0·53
S . .	abs.	abs.	0·01	abs.	0·01	0·02
MnO .	0·16	0·24	0·12	0·27	0·03	0·07
Total .	100·35	100·22	99·72	100·32	100·66	99·74

Norms and Classification.

	1.	2.	3.	4.	5.	6.
Qu. .	7·74	—	16·74	2·40	32·82	27·36
Or. .	12·79	19·46	12·79	21·13	25·02	22·24
Ab. .	23·06	22·01	27·77	22·53	23·66	20·96
An. .	19·13	17·24	23·33	16·40	5·84	14·18
Ne. .	—	1·14	—	—	—	—
Co. .	—	—	—	—	3·47	1·53
Di. .	15·85	12·98	1·61	14·70	—	—
Ol. .	—	14·75	—	—	—	—
Hy. .	13·83	—	12·49	14·31	3·69	9·41
Mg. .	3·71	2·78	0·70	1·39	2·09	0·70
Il. . .	2·00	5·32	1·52	3·95	0·46	1·67
Ap. .	0·62	3·36	1·34	1·80	1·24	1·24

Anal. No.	*Classification.*
1.	II(III).(4)5.4.″4.
2.	(II)III.5.(3)4.3″.
3.	″II.4.3″.4.
4.	II(III).5.(3)4.3.
5.	I″.3(4).3.3.
6.	(I)II.″4.(2)3.3.

TABLE I (*continued*).

	7.	8.	9.	10.	11.	12.
SiO_2 .	67·07	65·45	62·23	61·64	63·99	72·63
Al_2O_3 .	15·55	17·03	16·84	15·73	17·27	14·12
Fe_2O_3 .	0·50	0·33	0·36	0·46	0·97	0·22
FeO .	3·38	3·88	2·47	6·19	3·65	1·39
MgO .	1·69	1·62	1·93	3·54	2·81	0·59
CaO .	2·97	3·29	7·16	2·94	0·48	0·64
Na_2O .	3·21	2·79	6·88	2·84	1·06	2·62
K_2O .	3·80	3·21	0·89	3·64	5·42	4·99
H_2O + .	1·02	0·70	0·32	1·10	2·30	1·93
H_2O − .	0·15	0·08	0·23	0·07	0·58	0·23
CO_2 .	0·12	0·03	0·15	0·02	tr.	0·10
TiO_2 .	0·61	0·93	0·56	1·14	1·08	0·26
P_2O_5 .	0·23	0·70	0·12	0·15	0·11	0·12
S . .	0·04	0·01	0·01	tr.	abs.	0·09
MnO .	0·04	0·05	0·04	0·09	0·03	0·04
Total .	100·38	100·10	100·19	99·55	99·75	100·01
Loss 0 for S .	0·01					0·03
	100·37					99·98

Norms and Classification.

Qu. . . .	23·76
Or. . . .	22·24
Ab. . . .	27·25
An. . . .	12·79
Co. . . .	1·43
Hy. . . .	8·95
Mg. . .	0·70
Il. . . .	1·22
Ap. . .	0·62

I(II).4.2(3).3″.

Modes.

	1. Granodiorite.	2. Adamellite.
Quartz .	24·1	32·4
Plagioclase .	33·7	22·6
Orthoclase .	20·4	17·6
Biotite .	18·9	15·4
Amphibole .	1·7	—
Ilmenite .	0·7	n.d.
Cordierite .	—	11·6
Total . .	99·5	99·6

INDEX TO ANALYSES.

1. Andesitic basalt, Blue Hills, Taggerty.
2. Meta-basalt, Keppel's Lookout, Marysville. (K. L. 8.)
3. Meta-andesite, Robley's Spur, Marysville. (R.*b*.)
4. Meta-andesite, Robley's Spur, Marysville. (R. 12.)
5. Fragmental toscanite (fine-grained facies), Cumberland. (C.l.)
6. Rhyodacite, Wood's Point Road, Marysville. (G. 22.)
7. Granodiorite, Talbot Drive, Marysville. (M. 3.)
8. Biotitized sandstone, Wood's Point Road, Marysville. (G. 15.)
9. Albitized diopsidic xenolith in granodiorite, Talbot Drive, Marysville. (T. D. 2.)
10. Granitized meta-basite in granodiorite, Talbot Drive, Marysville.
11. Xenolith in granodiorite, Talbot Drive, Marysville.
12. Aplite, granodiorite contact, Talbot Drive, Marysville.

Analyst: E. S. HILLS.

IV. STRUCTURE AND RELATIONS OF THE COMPLEX.

Recent advances in the interpretation of the Upper Palaeozoic stratigraphy of Victoria enable us to arrive at a new conception of the rôle played by vulcanicity in that State during the Devonian Period. It will be clear from the discussion in an earlier paper

(Hills, 1931) that great masses of acid lavas, the partial extent of which may be gathered from the locality map (Fig. 1), were extruded in Upper Devonian times. These lavas underlie the red beds of the Eastern Upper Palaeozoic Belt and it is most probable that they originally covered the whole of the area shown in the map (and perhaps much more) to a depth of 2,000 feet to 4,000 + feet, often, as at Marysville, with very little intercalated sedimentary material. The total area covered was of the order of 8,000 + square miles, so that something of the nature of a cataclysm of lavas, mainly acid, must have overwhelmed Victoria in Upper Devonian times. On general grounds alone it is inconceivable that such outpourings should have resulted from vulcanicity of the central type, but must have been produced either from fissure eruptions or by a process of roof foundering. Although, however, granitoid rocks came very close to the surface subsequent to the vulcanicity, there is no evidence of that continuous gradation from lavas to plutonic rocks that might have been expected had roof foundering in the usual sense of the word taken place. On the other hand, one can point to many tabular bodies of granodiorite-porphyrite such as that near Buxton, which may well have served as dyke feeders of rhyodacite fissure eruptions. The dyke swarm of the Wood's Point auriferous belt, in which rocks ranging from ultrabasic to acid occur, has been shown in another place to be one of the manifestations of the Upper Devonian igneous activity, and is a probable locus of extrusion of lavas similar to those of Marysville and Cumberland. That small volcanoes of the central type were developed in connection with the fissures is practically certain, but in the Marysville complex pyroclastics are limited in their occurrence, and it is probable that the great rhyodacite-toscanite-nevadite extrusion was a continuous and gigantic eruption from major fissures.

The present disposition of the lavas is a matter of some importance, especially whether they are synclinally folded or not. Certainly they dip rather steeply to the east on the Marysville side, and reappear in the east, at Cumberland, but it is conceivable that faulting rather than folding may have produced a basin shape; and fault movements were certainly important at the time of extrusion, and presumably also afterwards. The fact that the western edge of the Eastern Upper Palaeozoic Belt is generally faulted suggests that the dip of the lavas at Marysville and Taggerty may be due to the same cause.

V. CONCLUSION.

The conception of Victorian Siluro-Devonian earth-history accepted until recently was that at the close of the Silurian Period and early in the Devonian great earth movements of orogenic nature took place, being accompanied by igneous activity—extrusion of the " dacites ", and intrusion of the granodiorites and other plutonic rocks. It has recently been shown that all that was needed for the proof of the Upper Devonian age of the dacites in the Marysville complex was the demonstration of their close relation to the nevadites. The geology and petrology of Marysville give clear proof that such a close relationship does indeed exist, and their Upper Devonian age seems satisfactorily demonstrated. The various igneous and sedimentary rocks of far eastern Victoria remain, however, very difficult to interpret, and especially is this true of the north-eastern metamorphic belt dealt with so fully by Tattam (1929), for although he correlated the granitoid types occurring there with the " Lower " (now Upper) Devonian igneous activity, we do not seem to be able to raise them up in the succession with the dacites and other lavas, for Howitt says that they are overlain by the Middle Devonian Bindi limestone. Until further research has been carried out, little is to be gained by discussion of the question; and the proof of the post-Lower Carboniferous age of certain granodiorites in the Grampians shows that the problems of igneous activity in Victoria in Upper Palaeozoic times are by no means solved.

In conclusion, I should like to thank Dr. H. S. Summers for encouragement during the earlier stages of the work, and Mr. F. .A Singleton for the use of rock specimens from Marysville, and some notes on that locality. The instruction by Dr. H. F. Harwood in rock analysis and the discussion of many petrological problems by Dr. A. Brammall was much appreciated; Professor C. E. Tilley made a brief revision of the work, suggesting improvements to the text and in the method of presentation, for which I am very grateful.

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EXPLANATION OF PLATE IX.

Igneous Rocks from Marysville, Victoria.

Fig.

1.—Albitized diopsidic xenolith in granodiorite. × 18. Crossed Nicols. Contains analbite (cross-hatched), antiperthite, quartz, and secondary tremolitic amphibole after diopside.

2.—Edge of a meta-andesite fragment in a hybrid rock. × 18. Crossed Nicols. Shows the development of biotite and increase in grain-size as the junction with the acid host rock is approached.

3.—Granodiorite. × 18. Ordinary light. Shows a group of small jacketed plagioclase xenocrysts.

4.—Hybrid rock from below Keppel Falls. Slightly less than natural size. Shows dark xenoliths of meta-andesite and leucocratic schlieren.

5.—Lower Toscanite. × 18. Ordinary light. Shows a fine-grained schliere (S), a meta-basalt xenolith (X), and shattered phenocrysts of quartz and felspar.

6.—Sedimentary xenolith in adamellite. × 18. Ordinary light. Composed of garnet, cordierite, pinite, biotite, zircon, ilmenite, and quartz.

The Permian Shell-Limestone Reef beneath Hartlepool.

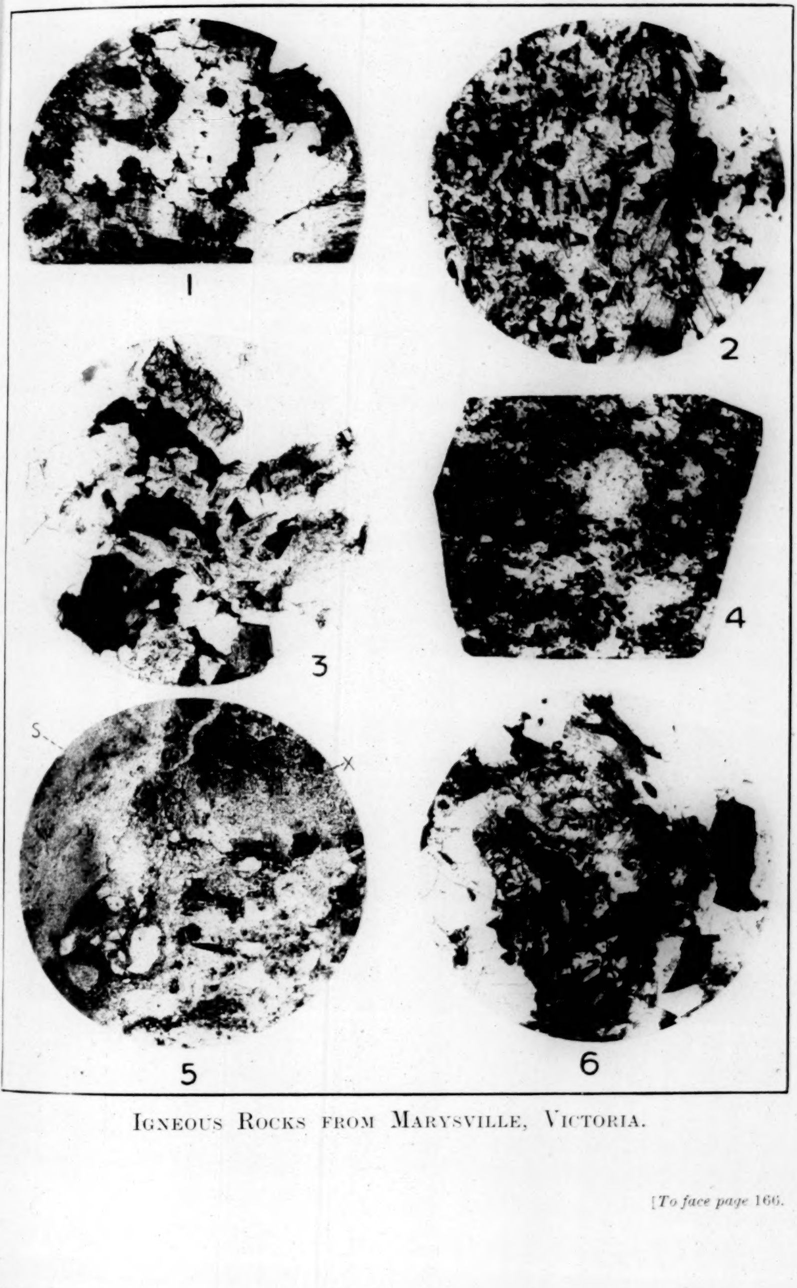
By C. T. Trechmann, D.Sc., F.G.S.

THE question whether the Permian Shell Limestone Bryozoa Reef of the Middle Magnesian Limestone exists below the Upper Magnesian Limestones in the Hartlepool district was answered in the affirmative about two years ago, when a boring was sunk to a depth of 225 feet at West Hartlepool Waterworks (W on the sketch-map).

The Shell Limestone extends as a chain of reef knolls from Down Hill on the Permian escarpment in the north, to Hesleden Dene in the south, some 4 miles north-west of Hartlepool, where it disappears under Upper Permian and Boulder Clay. It gradually widens and thickens as it passes south, and is flanked on the east by unfossiliferous and on the west by very scantily fossiliferous bedded dolomites.

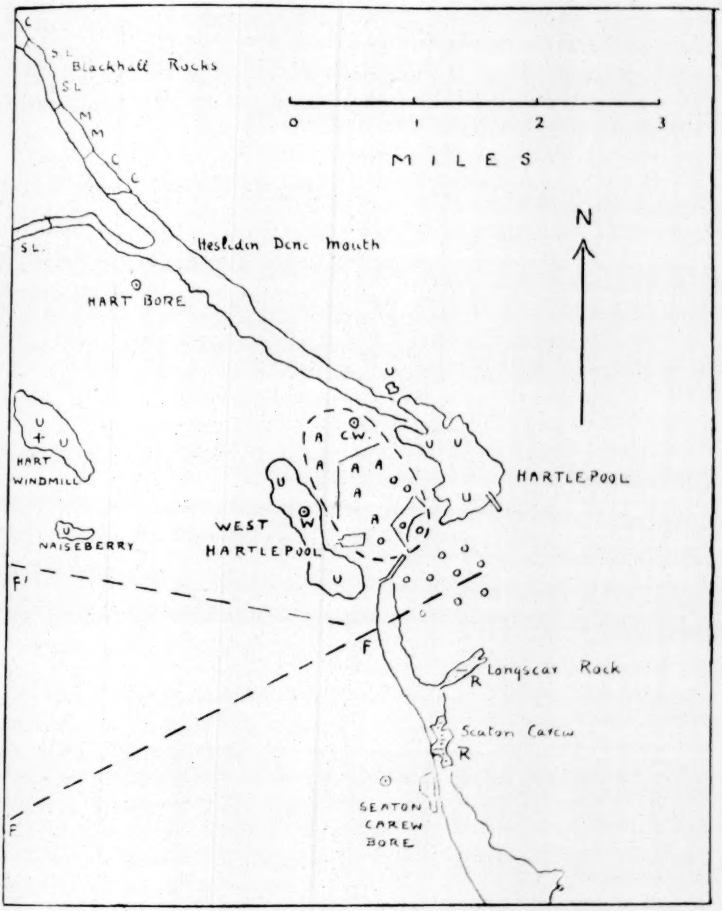
The boring in question was started at an altitude of about 25 feet in an old quarry in the Upper Magnesian Limestone which forms the mass that crops out on the west of the railway line that connects Hartlepool and West Hartlepool. All this exposure, which extends to the south-east and passes under Church Street, West Hartlepool, consists of soft friable, well-bedded, frequently oolitic Upper Magnesian Limestone of the Hartlepool and Roker Series.

Rather more than a mile to the east the old town of Hartlepool stands on a similar mass of Upper Magnesian Limestone, but among



Igneous Rocks from Marysville, Victoria.

[To face page 166.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U
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Longscar Rock
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Seaton Carew
R
SEATON CAREW BORE
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FIG. 1.—Geological Sketch-map of the Hartlepool District.

C.C.: Outcrops of Concretionary or Cannon-ball Limestones on the coast. S.L.: Shell Limestone reef, interbedded conglomerate (Bed "C" with an impoverished fauna) on the coast at Blackhall Rocks and in Hesleden Dene. M.M.: Middle unfossiliferous dolomites overlying the latter. U.U.: Upper Magnesian Limestones; the Hartlepool and Roker beds. A.A.: Probable area of the anhydrite at about 100 feet depth between Hartlepool and West Hartlepool; its supposed outline indicated by the dotted oval space. O.O.: Boulders of gypsum torn up from the latter and distributed in the drift to the south and south-east. R.R.: Triassic red sandstones at Longscar rock and Seaton Carew. ⊙: Boreholes. W.: Waterworks boring, West Hartlepool, described in this paper. C.W.: Warren Cement Works borings, Hartlepool. F.F.: Generally surmised direction of the fault below the glacial beds. F'F.: Suggested direction on the supposition that it connects up with a fault that lies to the south and west of Coxhoe.

this a fairly massive bed of dolomitic oolite occurs. A similar suite of Upper Magnesian Limestone fossils occurs at both outcrops, which include *Schizodus schlotheimi* Gein., *Mytilus septifer* King, *Pleurophorus costatus* Brown and a few small gasteropods. In the intervening depression, in which the docks of the two towns are constructed, we meet with blown sand or estuarine silt about 22 feet thick; submerged forest or peat bed about 8 feet; glacial deposits some 67 feet; and then we come on solid rock at a depth of about 97 feet. This at the top is gypsum for 1 or 2 feet and then passes down into anhydrite, 265 feet, and then goes down into gypsum or gypsum-bearing magnesian limestone. The only borings that have proved the existence of this anhydrite were put down at the Warren Cement Works (C.W. on the sketch-map), at what seems to be the north-eastern corner of the mass, one of them in the year 1888,[1] and three more in 1923.[2] The anhydrite varies in thickness from 180 feet to 265 feet, and has since 1923 and till quite recently been mined for use in the production of synthetic ammonium sulphate, and it is estimated that about 750,000 tons have been obtained from beneath the Warren Cement Works. The precise extension of the anhydrite mass towards the west or south is uncertain, but its outline probably corresponds with the slack or depression between Hartlepool and West Hartlepool.

The only previous direct evidence that the Shell Limestone reef probably extended under Hartlepool was the finding of three species of Middle Permian reef fossils, *Strophalosia lamellosa* Gein., *Epithyris elongata* Schl., and *Bakevellia ceratophaga* Schl., in grey gypsum-impregnated dolomite a few feet below the anhydrite in the cores of the 1888 boring at a depth of about 383 feet.

It seems almost certain that the mass of anhydrite is an original deposit replacing some of the higher part of the Shell Limestone reef as well as a part of the upper dolomites. In the mine at the north end it was much hydrated to gypsum, and dipped suddenly down towards the north, as though it had been cut off by solution in that direction; while at its north-eastern side it tended to thin out and to dip, the dip possibly corresponding to part of the eastern slope of the reef. After much of it had been removed mining was stopped, as water was getting in from the north, and also from above, the blasting having shattered the mass to some extent.

When one went down the mine the anhydrite appeared hard and crystalline, and of a translucent bluish-white colour, in striking contrast to all the surface exposures of Magnesian Limestone which are generally very porous, powdery, or brecciated. Some years ago I proposed the idea that most of the collapse, porosity, brecciation, abnormal junctions, etc., of the Permian were due to removal by solution of anhydrite and gypsum which once existed disseminated through the formation ; and that this Hartlepool mass, owing to its exceptional size, had escaped complete removal.

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[1] *Quart. Jour. Geol. Soc.*, lxix, 1913, 185.

[2] *Proc. Geol. Assoc.*, xxxvi, 1925, 139.

Two and a half miles to the north-west of the Waterworks boring is an outcrop of Magnesian Limestone, on which Hart windmill stands at an elevation of about 200 feet. These beds appear to be the Upper Magnesian Limestone, but of a rather different character from those at Hartlepool, being harder and more segregated. They yield a few of the typical fossils, such as *Schizodus* and *Mytilus* (*Liebea*) *septifer*.

Three and a half miles to the north-west on the coast, at a place called " Cobbler's Shop " on the 1 in. map, the most southerly exposure of the Concretionary or Cannon Ball Limestone occurs. The concretionary structures are rather poorly developed and this bed, the lower of the two main divisions of the Upper Limestones, seems to pass out to sea to the south-east ; at any rate it dies away north of Hartlepool, as it was not met with in the Waterworks boring.

The nearest surface exposure of the Shell Limestone reef is at Blackhall Rocks on the coast, rather over 4 miles to the north-north-west of the Waterworks boring and in Hesleden Dene between the railway viaduct and the sea, 3¼ miles to the north-west. At both places the reef occurs as what R. House termed an " interbedded conglomerate ", and contains a restricted fauna in which the large brachiopods of the lower part of the reef have already died out, but such fossils as *Nautilus freieslebeni* still flourish. Overlying this Shell Limestone is a bed of dusty well-bedded dolomite, with many cavities but no fossils, which occupies the cliff for some distance south of Blackhall Rocks. South of this the Concretionary beds are brought down by a small fault.

Borings were sunk in 1917 near Sheraton and at Cotefield Close,[1] about 1½ miles east of Hurworth Burn Station. Both are 5–5½ miles west of Hartlepool, and the Sheraton boring is about 1¼ miles north of that at Cotefield Close. Both these borings commenced below a considerable thickness of drift (187 feet of it at Sheraton), on Middle Magnesian Limestones, the upper beds not having extended so far west as this. The middle beds were 213 feet thick at Sheraton and 240 feet at Cotefield Close ; in the Sheraton bore a bed with a few fossils occurred, showing that we have the equivalent of the middle beds on the western side of the reef similar to the beds west of the reef in Castle Eden Dene. The Lower Magnesian Limestone was 286 feet thick at Sheraton and 271 feet at Cotefield Close. The Marl Slate was 1 foot and 1¼ feet respectively, and the Yellow Sands were 3½ feet thick at Sheraton but absent at Cotefield Close. These borings prove that the Shell Limestone reef dies out somewhere between the West Hartlepool Waterworks and Sheraton, 4½ miles to the west ; and affords further evidence of the reef knoll-like nature of the Shell Limestone.

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[1] Geol. Mag., LVI, 1919, 163.

Boring to a depth of 225 feet at West Hartlepool Waterworks in an old quarry adjoining the main road, and west of the railway line

		Approx. thicknes in feet.
Upper Magnesian Limestones.	Upper bedded dolomites, hard and soft bands, the latter broken up in the boring, similar to rock exposed in the quarry. Fossils (in quarry). *Schizodus schlotheimi*, *Pleurophorus costatus*, *Mytilus* (*Liebea*) *septifer*	34
	Rather hard yellow platy dolomite (representing the equivalent in South Durham of the Flexible Limestone in the Sunderland area). No fossils	5
Unfossiliferous Middle Beds.	Porous yellow dolomite	12
	Soft yellow dolomite	6
	Broken up yellow dolomite with star-shaped cavities, apparently the result of solution of anhydrite crystal aggregates . . .	15
Upper part of the Shell Limestone Reef. Apparently with no Brachiopoda except *Epithyris*.	Soft dolomite broken up in the cores . . .	12
	Brown and yellow dolomite well bedded towards the top and much contorted . . .	25
	Hard whitish-yellow dolomite with calcite-lined cavities; small fossils at the base, *Byssoarca striata*; and small *Bakevellia antiqua* and *B. ceratophaga*.	50
	Yellow dolomite broken up in the core, with a hard splintery band containing dwarfed specimens of *Epithyris elongata*, and lower down another similar band full of *Turbo helicinus*, *Bakevellia antiqua*, etc.	33
	Yellowish dolomite fallen to powder in the boring	6
	Hard crystalline reef dolomite broken up in the core; *Epithyris elongata*, *Turbo helicinus*, *Pleurotomaria antrina* (small specimens) . .	3
Shell Limestone Reef, with *Strophalosia* and near the base *Productus*.	Grey and yellowish rather hard, and in places compact, reef dolomite; in other places it is a friable mush of decomposed *Bryozoa* and other reef fossils. *Fenestella retiformis* (small), *Synocladia virgulacea* (small), *Nautilus freieslebeni* (at about 200 feet down to base of the boring), *Epithyris elongata* (rather dwarfed), *Spiriferina cristata*, *Strophalosia lamellosa* (distorted and rather dwarfed examples); *Strophalosia morrisiana* (very small), *Productus horridus* (very dwarfed, commencing at a depth of about 220 feet), *Camarophoria globulina*, *Streptorhynchus pelargonatus* (small), *Byssoarca striata*, *Pseudomonotis speluncaria*, *Bakevellia antiqua*, *B. ceratophaga*, *Schizodus truncatus*, *Mytilus* (*Liebea*) *septifer*, *Turbo* cf. *thomsonianus*, *T. helicinus*, *T. taylorianus*, *Macrocheilus symmetricus* (rather plentiful); and small turreted shells, either *Loxonema fasciata* or *L. geinitziana*. Dolomitized algae, etc. Bands of small gasteropods and other small fossils occur at various levels.	24

At Blackhall Colliery sinking, 5½–6 miles north-west of Hartlepool, the total thickness of the Permian was 688 feet,[1] and the upper beds, including the Concretionary Limestone, overlay the reef. In a boring at Hart Station, 3 miles to the south-east of Blackhall, the Permian was 708 feet thick. At Seaton Carew boring, 2 miles south of Hartlepool, and south of the great fault, the greatest recorded thickness of the Magnesian Limestone, 878 feet, was encountered below the Triassic Red beds. About 7 miles to the south-west, at Whitehouse, near Norton,[2] the thinnest recorded complete section of the Magnesian Limestone, 299 feet, underlying the red beds was recorded. There is little doubt that the great eastward thickening is due to the incoming of the reef and the Upper Limestones.

The hidden or buried fault that brings down the red beds south of Hartlepool is shown on the 1 in. Geol. Survey Map as passing in a south-westerly direction. It seems to me more likely that it may pass rather north of west and connect up with a fault just south of Raisby Hill limestone quarries and Coxhoe Hall, that carries the Magnesian Limestone escarpment out to the south-west beyond Ferryhill. It is thus indicated on the old hand-coloured geological survey map of England by Sir A. C. Ramsay in 1879.

After this preliminary discussion we may now turn to the details of the boring in question, W on the sketch-map. (See p. 170.)

Observations on the Boring.

The Upper Limestones persist to a depth of about 40 feet. There is no trace of the Flexible Limestone in the form in which it occurs in the northern part of Durham, but a hard platy rock replaces it in the south and occurs also in Hesleden Dene, where it overlies the highest beds of the reef. No Concretionary or Cannon-ball Limestone was seen in the Waterworks boring: perhaps it is too far west and south for this rock, which appears on the coast 3 miles to the north-east, and also occurred on top of the eastern part of the reef in Blackhall Colliery sinking. The Concretionary beds seem to have been laid down on the eastern side and flanks of the Shell Limestone ridge, and the Cannon-ball structure tends to weaken the farther we get away from the reef.

The remainder of the boring was in Middle Magnesian Limestones to a depth of 225 feet, the higher beds are unfossiliferous bedded dolomites, such as one sees overlying the interbedded fossiliferous reef at Blackhall Rocks. Fossils commence at a depth of about 109 feet, and in descending an increasing number of forms is met with, the boring just going a few feet into the top of the *Productus horridus* zone, dwarfed specimens of which were met with. It did not reach the lower beds of the Shell Limestone reef with such fossils as

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[1] *Quart. Jour. Geol. Soc.*, lxix, 1913, 213.

[2] *Quart. Jour. Geol. Soc.*, xlviii, 1892, 490.

Spirifer alata, *Camarophoria multiplicata*, *Cleiothyris pectinifera*, *Pleurotomaria nodulosa*, etc., which comprise the main fauna near the base of the reef, and which are among the first to become extinct.

Assuming the thickness of the Permian below Hartlepool to be at least 700 feet, there should be perhaps below the level reached by the boring another 200 feet of Shell Limestone reef, and possibly 275 feet of Lower Limestones, with a few feet of Marl Slate below it. The Yellow Sands being intermittently distributed may or may not exist beneath Hartlepool. The Lower Limestone thickens as one goes south in Durham, and the reef also becomes wider and thicker. Unfortunately the boring could not be carried further, owing to the quite possible danger of the sea getting in and making the water brackish. If it could have been carried further down one would expect more and more of the Shell Limestone reef fauna, similar to the suite that was met with towards the base of the reef in the Blackhall Colliery sinking.

Hartlepool and West Hartlepool are among the few towns of considerable size which find themselves in the fortunate position of being able to supply their household and drinking water from the rock immediately below. The water, though very hard, is obtained in large quantities from about the level of the Shell Limestone in the restricted area of this old quarry. It seems probable that the water falls as rain over a considerable area to the north and west, on the outcrop of the Shell Limestone and its bedded western equivalents in the area about Horden, Easington, Wingate, etc., and flows through the broken and fissured reef rock and generally down the dip slope of the Permian to the south and east, till it approaches Hartlepool, when it is held up on the east by the hidden mass of impervious anhydrite, which lies under the depression between Hartlepool and West Hartlepool. Its further flow to the south is probably stopped by the east and west fault north of Seaton Carew, which must present a wall of impervious red sandstones and marls to impede the further progress of the water. The result is that almost anywhere beneath West Hartlepool a copious, almost artesian, supply of water can be obtained. If the boring had been carried lower still to below the level of the anhydrite mass, it is quite understandable that sea-water might penetrate the lower beds of the reef and render the water at those levels unserviceable.

Note on the Fossils Collected from the Cores in the Reef.

Polyzoa, etc.

Thamniscus dubius Schl.

A small mass, 31 mm. in diameter, with the apex of attachment.

Synocladia virgulacea Phill.

A mass, 45 mm. in diameter, showing the apex and cavities of the rootlets in a dolomite made up of debris of Bryozoa.

Fenestella retiformis Schl.

Small, mostly broken, pieces, with a small mesh.

Calamopora macrothii Gein.

A fragment rather low down in the boring.

Mammillopora mammillaris King.

A specimen resembling King's figure, pl. ii, fig. 3, but smaller, less mammillated, and less regular in growth.

Coral (?).

A curious branching, coral-like structure, 23 mm. high, not unlike a small form of *Syringopora*, the finer structure obliterated by dolomitization. Unlike anything figured by King.

Brachiopoda.

Strophalosia morrisiana King.

Dwarfed specimen, about 8 mm. across.

Strophalosia goldfussi Münst.

Dwarfed and distorted specimens up to 14 mm. in diameter, fairly low down in the boring.

Productus horridus Sow.

Specimens from the boring are 19 mm. wide and 13 mm. long, less than half the usual diameter of specimens from the lower beds of the reef. According to a table of zones, four in number, A, B, C, and D, proposed by me for the Shell Limestone reef,[1] *Productus horridus* persists to the top of zone B. The Hartlepool boring thus just penetrates into bed B.

Streptorhynchus pelargonatus Schl.

Ventral valves of two specimens.

Spiriferina cristata Schl.

One specimen, 9 mm. wide, resembling King, *Perm. Mon.*, pl. viii, fig. 12 ; near the base with dwarfed *Productus horridus*.

Epithyris elongata Schl.

Near the top of the Shell Limestone very small specimens, 4·5 mm. long, with loops only descending (*Centronella*-like stage). Lower down a slender specimen, 11·5 mm. long, with loop descending and ascending again (*Epithyris* stage), the shape of specimen figured by King, pl. vi, fig. 35. Another thick, fat, variant, 13·5 mm. long and 13 mm. wide, and 9 mm. thick, resembling King, pl. vii, figs. 3, 5, and 9, called by him *Epithyris sufflata* Schl.

Lamellibranchiata.

Schizodus truncatus King.

A specimen with both valves, 15 mm. wide and 11 mm. high, like King, *Perm. Mon.*, pl. xv, fig. 25 ; rather high in the reef in a hard dolomite.

Bakevellia antiqua Münst.

Specimens 11 mm. long commence near the top of the reef at a depth of about 192 feet, and become rather larger lower down.

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[1] *Proc. Geol. Soc.*, xxxvi, 1925, 139.

Bakevellia ceratophaga Schl.

This species commences at the top of the Shell Limestone reef and becomes larger on descending, up to 18 mm. long. The specimens are dwarfed and distorted near the top, resembling *B. tumida* King, *Perm. Mon.*, pl. xiv, figs. 35–7, which are probably only dwarfed specimens of the one species. Also the long and slender variety with foliaceous growth-lines occurred, like *B. sedgwickiana* King. A winged variety resembling *B. bicarinata* King was also collected.

Monotis speluncaria Schl.

One convex valve, 35 mm. long, of the large flat variety with foliaceous or squamose growth-lines ; also another convex valve of a smaller more arched and slightly ribbed variety occurred rather well down in the reef. A fragment of another specimen was found higher up. At Claxheugh and elsewhere I have seen the small arched and ribbed form growing into the foliaceous type, resembling *M. garforthensis* King.

Byssoarca tumida J. Sow.

Dwarfed specimens 19 or 20 mm. long, with wide and thickened area and more or less arched and distorted shells, were common in the middle part of the Shell Limestone reef. Nearer the top very small but not distorted specimens occurred.

Gasteropoda.

Euomphalus permianus King.

A small specimen 2 mm. in diameter like King, *Perm. Mon.*, pl. xvii, fig. 10–12.

Macrocheilus symmetricus King.

Several specimens up to 10 mm. long with less rounded whorls and less sunken sutures than in King's figure, pl. xvi, figs. 32–3; rather low down in the boring. Another larger fragment is more like King's figure.

Loxonema cf. *geinitziana* King.

One specimen 6 mm. high in a mushy dolomite may belong to this species, King pl. xvi, fig. 31.

Pleurotomaria antrina Schl., or *P. tunstallensis* King.

One specimen, rather high up in the reef, 6 mm. wide and 5 mm. high, with a well-incised slit band.

Natica leibnitziana King.

One or two poorly preserved specimens.

Turbo helicinus Schl., and possibly *T. mancuniensis* Brown.

Specimens 8 mm. high, with well-marked ribs, some of them with finely foliaceous growth-lines commence rather high up in the reef.

In the highest splintery dolomites of the reef smaller dwarfed specimens with more elongated spire and fainter ribs occur.

Turbo cf. *thomsonianus* King.

Small specimens occurred in the higher parts of the Shell Limestone.

Turbo cf. *taylorianus* King.

Ditto.

Cephalopoda.

Nautilus (*Peripetoceras*) *freieslebeni* Gein., or *N. bowerbankianus* King.

Two or three broken specimens, about 25 mm. in diameter, occurred in the lower part of the boring. They commence to come in rather above the level of *Productus horridus.*

Further Notes on the Huntingdon Road Gravels, Cambridge.

By J. E. Marr, Sc.D., F.R.S., and W. B. R. King, M.A.

As it is unlikely that we shall have an opportunity of collaborating in further work on the Pleistocene deposits of the Cambridge area, we wish to add some short notes to our earlier work.

Firstly we would refer to the uneven-bedded gravels of the Traveller's Rest Pit. We have for some time regarded these as outwash gravels from an oncoming ice-sheet before it reached Cambridge, but we do not appear to have published this view, which has been accepted by several geologists to whom we have shown the evidence.

In our paper " Notes on the Pleistocene Deposits of the Cambridge District ",[1] we suggest on p. 311 their formation under tundra conditions. The term is used there as indicating that the type of deposit was of the character of the accumulations found in the tundras, not that the whole area was necessarily under tundra conditions, for there are patches of tundra-like accumulations in Greenland, for instance, outside the edge of the ice, resembling the true deposits of the tundra on a small scale. We wish here to call attention to the similarity between the Traveller's Rest uneven-bedded gravels and the outwash deposits of the flood-plain in front of the Malaspina glacier.[2] On the flood-plain in front of the glacier, streams issuing from the ice deposit gravels of various degrees of coarseness, and from these streams in flood-time water enters into depressions of the tract built up of these gravels, forming lakelets and ponds of various sizes in which finer material is deposited. In these deposits Russell found *Limnaea* in abundance.

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[1] J. E. Marr and W. B. R. King, Geol. Mag., LXV, 1928, 307–12. We wish to call attention here to an unfortunate slip in proof-correcting in the above-mentioned paper, where on p. 311 line 17, " upper unevenbedded gravels " appears for " upper evenbedded gravels ".

[2] I. C. Russell, 13*th Annual Report U.S. Geol. Surv.*, part iii, 17.

In the description of the uneven-bedded gravels of the Traveller's Rest,[1] the occurrence of even-bedded fine gravels, sands, and loams of small thickness and lateral extent is noted, interstratified with the usual uneven-bedded deposits. The loams are well laminated, and contain shells, but as noted by Kennard no truly aquatic species is present, though *Limnaea truncatula* occurs. The other shells are *Pupilla muscorum*, *Columella columella*, and *Succinea oblonga*. This accords with the idea that these small, lenticular patches of laminated and regularly-bedded deposits in the normal irregular-bedded deposits of the " uneven-bedded series " were formed by frozen material being curved into depressions as in the Malaspina Glacier flood-plain, and that the shells were washed into them, or in the case of the *Limnaea* may have lived in the ponds. The abundance of land-fauna is quite in accordance with the nature and occurrence of the deposits, which must have been formed in quite small, probably temporary ponds, into which an aquatic fauna had not been introduced.

Even the finest loam of the shell-bearing beds is not a glacier mud, but a very fine silt, apparently not derived directly from the glacier streams, but washed out of the uneven-bedded gravels. Much of the Malaspina Glacier is covered with dense vegetation, but hitherto no trace of vegetation has been found in the Traveller's Rest. It may yet be found associated with the loams.

The next part of this note deals with new sections in the same neighbourhood. In January, 1930, several trial holes were dug in the pasture to the north of, and adjoining, the Christ's and Sidney Colleges' Athletic Ground, on the Huntingdon Road. We decided to use some of the Gordon Wigan Fund, which had been allotted for excavations in the Pleistocene deposits of the Cambridge district, in an attempt to discover the relationship of the clays underlying the playing field to the gravels.

The clays of this locality are part of the large spread of " clay-with-race ", the characters of which have been discussed by one of us in previous papers.[2]

During recent years a deep sewer has been laid along the Huntingdon Road, and the evidence from this, together with the excavations to be described below, enables us to deduce the relationship of the clay-with-race to the gravels on the north and south of the Huntingdon Road.

The first group of excavations was made on the eastern side of the field adjoining the Athletic Ground. A trench 4 yards long was dug about 6 feet deep and this was deepened another 2 feet at two points; besides the trench, four trial holes were dug and small auger holes made in the bottom of these. The resulting section is shown in the diagram (Fig. 1).

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[1] Marr and King, Geol. Mag., LXV, 1928, 308.

[2] J. E. Marr, *Quart. Jour. Geol. Soc.*, lxxv, 1920, 220; and J. E. Marr, ibid., lxxxii, 1926, 126.

At point X a loamy band in the sand yielded a good collection of mollusca, of which the following have been identified [1] :—

Cochlicopia lubrica (Müller)
Pupilla muscorum (Linn)
Trochulus hispidus (Linn)
Succinia pfeifferi (Rossmässler)
Succinia putris (Linn)
Vallonia costata (?) (Müller)
Petacina fulva (Müller)

From the distribution of the strata, it is quite clear that the clay-with-race overlies the shell-bearing sands and gravel, although in hole 2 a pocket of gravel with shells occurred in the clay.

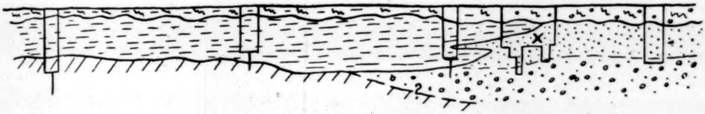


FIG. 1.—Section through trench and four pits.

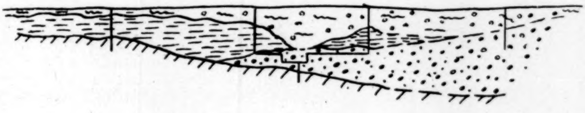
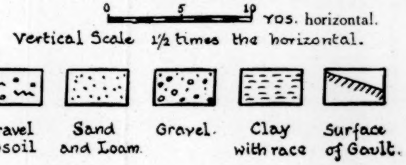


FIG. 2.—Section through trench and two bore-holes.



The second group of excavations was made near the centre of the field and was dug at the junction of the clay and gravel, as far as could be judged from the type of surface soil and a few tests with the hand auger. The result was to prove a similar succession with a gravel, which yielded a few shells similar to those in the first excavation, lying above the Gault. Here, however, a wash of brown sandy loam had been carried down the slope, formed of the gravel outcrop. This gave the appearance of a wedge of clay-with-race between two gravels (Fig. 2).

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[1] We have to thank Mr. A. S. Kennard and Mr. Oakley for checking over and correcting the identifications from this locality. Mr. Kennard compares the faunule to that of Barnwell Abbey.

The surface of the existing playing field is formed of clay-with-race; this probably rests directly on the Gault. Certainly, this is the case on the Huntingdon Road, where undisturbed Gault, lying below the clay-with-race, is proved in the deep sewer along the whole length of the road from Storey's Way to beyond the National Institute of Agricultural Botany. In this sewer the clay-with-race is of variable thickness; the lower part is probably Gault puddled in situ, while the higher parts appear to be puddled Gault in which there are a few scattered flint fragments, showing that it has been disturbed or re-deposited through some agency.

It would seem that the clay-with-race may be of a different origin in different cases, and that it does not necessarily belong to one particular stratigraphical horizon. It has been recorded from below the Traveller's Rest gravels,[1] and a patch occurs on the University farm in the gravels a little to the west of the Traveller's Rest pit. Similar deposits of clay-with-race are mapped as Gault in the bottoms of the valleys near Girton village; these latter deposits are clearly the infilling of the deep valleys cut in the Gault at the time of the formation of the buried channel of the Cam, and were probably filled with clay-with-race formed by the washing down of weathered Gault from the surface in Neolithic times.

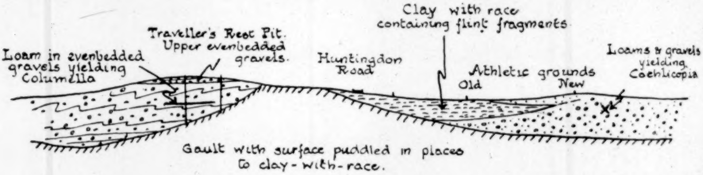
Clay with race containing flint fragments
Traveller's Rest Pit.
Upper evenbedded gravels.
Loam in evenbedded gravels yielding Columella
Huntingdon Road
Athletic grounds
Old
New
Loams & gravels yielding Cochlicopia
Gault with surface puddled in places to clay-with-race.

FIG. 3.—Diagrammatic section across the Huntingdon Road, Cambridge.

Returning to the Huntingdon Road sections, we consider we are in a position to construct a generalized section across the exposures (Fig. 3).

On this interpretation, the main mass of clay-with-race on the north side of the Huntingdon Road would be newer than the uneven-bedded gravels of the Traveller's Rest, while the shell-bearing gravels described above would be slightly older than, or nearly contemporaneous with, the main mass of the clay-with-race forming the surface of the playing field. This agrees with the conditions observed in the Oxford Road drain cutting.[2]

The shell-bearing gravels in the excavations would then belong to one of the higher level deposits formed near the beginning of the period of denudation, following the Mousterian glaciation, when the rivers were beginning to re-excavate the gravels laid down during the period of aggradation preceding that glaciation.

This seems to be the first record of molluscan remains from gravels at this level.

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[1] Marr, *Quart. Jour. Geol. Soc.*, lxxvi, 1920, 221.

[2] Ibid., lxxxii, 1926, 127, fig. 4.

Notes on the Geology of North Rona.

By MALCOLM STEWART, Brasenose College, Oxford.

PHYSICAL FEATURES.

THE island of North Rona is situated in the North Atlantic Ocean, in latitude 59° 7′ 30″ North, and longitude 5° 49′ 30″ West, thus forming the apex of an almost equilateral triangle of sides approximately 40 miles; the other two points of the triangle being Cape Wrath and the Butt of Lewis. To quote Capt. Burnaby, the island has the shape of a decanter, with the neck towards the north. The maximum altitude of 355 feet is attained near the south-east end. This hill, together with two others of slightly less height, make up the central ridge of the island. The north end, marked on the map as Fianuis, is comparatively flat, and nowhere exceeds a height of 100 feet. There is a steep slope up to the central hill ridge, and then the contours drop slowly towards the south. The island is cliff-bound on all sides, there being no beach at all. The cliffs are sheer, and of considerable height, with the exception of the north and south-west ends. There are one or two minor skerries off these two points separated from the island by no more than 100 yards. There is, however, a larger skerry, Gealldruig Mhor, a third of a mile south of the south-east end. The island has a maximum length of one mile, with a maximum breadth of a like figure ; it has a sea coast of 5 miles, and a superficial area of 300 acres. The whole of the island is grass-covered with the exception of the extreme north and south-west points. On North Rona are to be found the ruins of a small church and one or two houses, showing the existence of a previous habitation. There has been no permanent population since 1844.

The nearest point of land to North Rona is the small island of Sula Sgeir, 11½ miles to the west. These two islands are counted as Hebrides and belong to the parish of Barvas in Lewis.

PREVIOUS LITERATURE.

Although there are many descriptions of the island, the first account of the geology of North Rona was by Macculloch (1),[1] who in 1814 read a paper on the occurrence of wolfram on this island. By 1819, however, he must have adopted the opinion that the wolfram was in reality magnetite (2). Later Heddle agreed with his second finding (6), and I myself have found no traces of wolfram here. I believe also that as yet it has not been definitely identified in Scotland. The same mistake with regard to these two minerals was made by Raspe with reference to Tiree (4).

In his *Description of the Western Isles* Macculloch states that Rona consists of gneiss, alternating with bands of hornblende-schist equalling or exceeding it in quantity and traversed by granite veins. Later, Heddle's account is practically the same as Macculloch's. He, however, noticed the remarkable change of dip in the rock, and the effect the granite veins had on the weathering of the cliffs (5).

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[1] Figures in parentheses refer to list of references at end of paper.

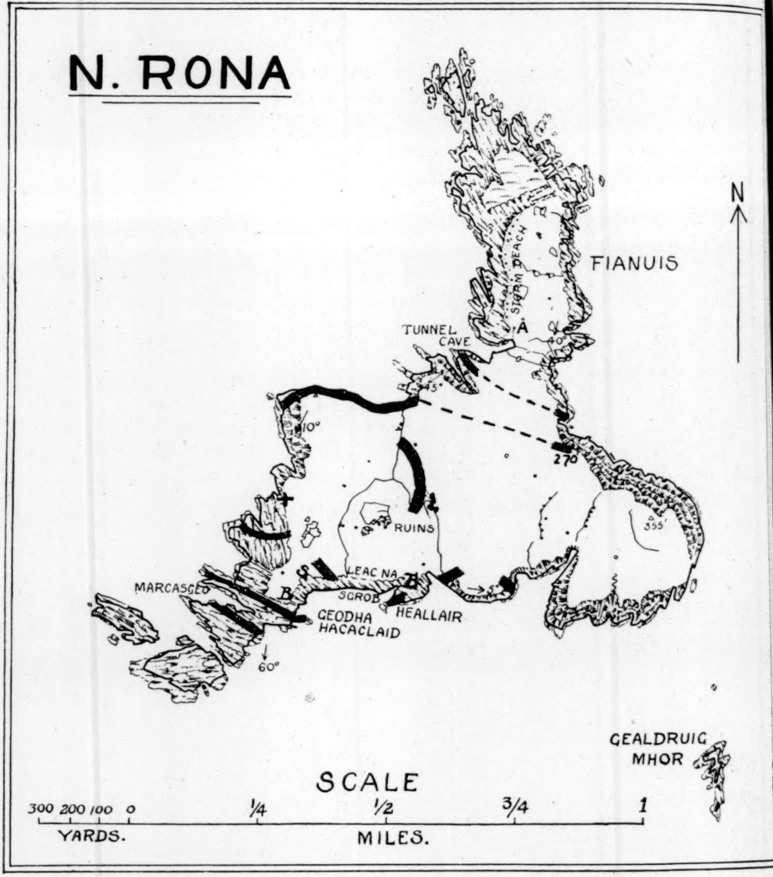
N. RONA
N
FIANUIS
STORM BEACH
A
40°
TUNNEL CAVE
45°
10°
270
RUINS
355
LEAC NA SCROB
B
S
B
MARCASGEO
HEALLAIR
GEODHA HACACLAID
60°
GEALDRUIG MHOR
SCALE
300 200 100 0
1/4
1/2
3/4
1
YARDS.
MILES.

Fig. 1.

A. Entrance to shaft.
B. Raised beaches.
S. Striae.
↙ Apparent dip of rocks.
▨ Outcrop of larger pegmatite veins.

His list of minerals of North Rona comprises quartz, magnetite, microcline, graphic granite, augite (sahlite), hornblende, and garnet (6).

The following is the result of personal observations during two brief stays on the island in the summers of 1930 and 1931.

GEOLOGY.

The rocks of North Rona have always been considered Lewisian in age. This is probably true, but there is no positive proof, and so far I have been unable to find rocks of an identical type anywhere in the Lewisian of the North-West Highlands.

For the most part the rocks of North Rona are intermediate in acidity, quartz usually being present in small quantities. Both orthoclase and plagioclase felspars are generally present, the latter being for the most part andesine. Microcline is also a common constituent. Ferro-magnesians are always present, and often make up 60 per cent of the rock. Hornblende is by far the most common, though a little augite is also sometimes to be seen. Garnet (iron-aluminium) may or may not be present, but where present it is always in a highly crushed state, never exhibiting any crystalline shape. These garnets are often over half an inch in diameter and occasionally show foliation. Commonly they form a line of weakness in the rock thereby rendering it more fissile.

The following is a description of a typical rock of the above type.

The unweathered hand specimen is jet black in colour and of moderately coarse texture, the cleavage faces of the hornblende reflecting a certain amount of light. The rock is studded with red garnets of average diameter of about a quarter of an inch. They are in a highly crushed state. Small white translucent crystals of felspar are also visible. The rock shows no apparent foliation. The specific gravity of this specimen is 3·12. The microscope shows that the rock is holocrystalline, the mineral constituents being for the most part of equal size, having a diameter of about 1 mm. By far the most common mineral is hornblende. This is of a green colour, and in all sections is very strongly pleochroic from dark green to light yellow-brown. Some crystals show one cleavage, while others show the two at 125°. The hornblende occupies nearly 40 per cent of the section. Almost colourless augite is present in fairly small quantity. Quartz can be seen in small quantity, and orthoclase in slight excess. The plagioclase which is abundant shows very distinct lamellar twinning, extinction on plates perpendicular to the twin plane being $-16°$. Both refractive indices are greater than 1·54 and the felspar shows all the characteristics of andesine. Pink garnet is present though badly shattered. Small pieces of magnetite are found associated with the hornblende.

The above type of rock is to be found anywhere on the main part of the island, the rocks of the north and south-west ends being, however, slightly different. Here the foliation of the rock is very much more noticeable, and results in the separation of the more acidic and basic minerals which gives a light and dark banded appearance to the rock. These " bands " are often 2 or 3 inches in width. Garnets are not found in this type of rock. A specimen of the more basic rock showed that the texture was very coarse and phanerocrystalline : this specimen was very similar to hornblendite. I have not been able to find any identical rocks on the mainland, but rocks of a very similar type are to be found in the Scourie and Loch Laxford districts of the North-West Highlands.

The whole of the island is intersected by pegmatite veins. These are of all sizes, the largest, however, seeming to be situated at the south-west end. Here some of the veins measure over 40 feet in breadth. The general trend of these veins is that of a north-west south-east direction. These veins play a very large part in the structure of the island. The whole of the cliff of the north face of the central hill ridge is composed of one enormous vein. This has undoubtably retarded the rate of erosion of this side. Most of the hill ridge is also composed of these veins, and they may be seen cropping out on the west side, and in numerous places on the steep slope up from the north end to the main part of the island. One of these terminates in, and forms, the small conical hill of 270 feet on the east side.

In these veins both the quartz and felspar crystals are very large and coarse. Well-formed crystals are exceedingly rare. The quartz is, for the most part, milky white in colour, though smoky and rose-pink are by no means uncommon. The felspar is microcline and though usually white or orange-yellow is occasionally salmon-pink. Small garnets are often to be found in these veins. The pegmatite sometimes shows " graphic structure ", but this is always coarse and better seen in the hand specimen than under the microscope.

The dip of the rock plays a very important part in the scenic features of North Rona. Where the dip is quite considerable, the continual weathering, down the escarpments so formed, results in numerous " geos " and caves which are such characteristic features here. Good examples of this may be seen anywhere on the north or south-west extremities, especially in Marcasgeo, which separates off the peninsula of Sceapull, and the famous tunnel cave that separates Fianuis from the main part of Rona. This tunnel cave is 50 feet high and extends inland for about 100 yards. The south side of the cave is composed of sheer cliff, but the north is for the most part sloping at an angle of twenty to thirty degrees. There is an interesting shaft that extends from the centre of the thin neck of land here and descends into the further end of the cave. The entrance to this shaft is a hole about 3 ft. 6 in. high and 9 feet broad. The shaft itself is 100 feet long and runs down the dip slope of the rock. The shaft has obviously been formed by the underground drainage of the land above. I mention this shaft as I do not believe it has been described previously.

The general dip of the rocks varies considerably, but is for the most part in a S.S.W. direction. On the west side of the northern peninsula it is as great as 50°, thereby causing small escarpments towards the north. These escarpments render the rock easily fissile to the hammer. The same is true of Sceapull, the south-west end. It is from here that the former inhabitants got the flags to make their " dry-stone " houses.

Two of the most interesting recent geological features of North Rona are the slickensiding and the storm beach. The slickensiding is to be seen on the cliffs south of the village, and best of all on the sloping rock in the west angle of what is known as Leac na Sgrob. Here there is the most amazing example of slickensiding; the breadth of the area affected being about 20 feet. The rock has been badly burnt and exhibits the results of intense metamorphism. The microscope clearly shows that hornblende has for the most part altered towards magnetite, this latter mineral now occupying 70 per cent of the section. The striae themselves are often as deep as a third of an inch and trend down the sloping cliff into the sea, i.e. in a southerly direction. To what is this slickensiding due? Tradition claims that when St. Ronan landed on the island on the back of a whale, he chased away the devil, who scratched the rock with his claws as he slipped over the cliff into the sea. Hence the name of this place is Leac na Sgrob (the scratched declivity). In the short time at my disposal it was difficult to see the cause for this slickensiding. It appears, however, that it bears some relationship to the intrusion of the pegmatite veins, a large one being in the immediate vicinity and overlooking this area. At present, however, it is impossible to state with any degree of certainty the cause of the intense dynamic force that must have been involved to create these striae.

The storm beach occurs on the west side of Fianuis and stretches almost its entire length, a third of a mile. Its average breadth is about 20 feet and it is 10 feet in height. The beach is composed of indigenous blocks often weighing many hundredweight. The height of the beach above the sea averages 70 ft., and it occurs at about 20 yards from the face of the cliff. Such is the strength of the sea that it must have broken off these huge boulders and lodged them here. The rock in this area is easily fissile, and the actual breaking up of the rock is not so difficult. This beach was seen by Macculloch and described by him (3).

GLACIATION.

Both the islands of North Rona and Sula Sgeir lie well within the 100 fathom line. The depth of the sea between Rona and Cape Wrath scarcely exceeds 50 fathoms, while between Rona and the Butt of Lewis a maximum of 65 fathoms is recorded. It was therefore always considered likely that the quaternary ice reached these islands: in fact, James Geikie " believed that it would be eventually found that the Caithness ice as it swept out over the bed of the Atlantic and was joined by the great glaciers that poured northwards from the rugged glens of Sutherland, overflowed the little islets of North Rona and North Barra (Sula Sgeir) lying rather more than 40 miles north of the Butt of Lewis " (7). Geikie states that he had never been to Rona, but had heard the stories of the scratched rock and put them down to glacial striae. He, however, was mistaken here, the only striae on Rona being the slickensides obviously caused by differential land movement. Glacial striae are wholly absent from Rona. Confirmation of his general opinion, however, is found in the occurrence of small boulders of Torridon Sandstone in the storm beach. One may suppose from the presence of these that at one time there were probably more erratics on the island, which have now disappeared, the only ones now remaining being lodged in the storm beach.

There is also the strong probability of there being a raised beach on North Rona. The possibility of there being a raised beach here was first entertained by Mr. D. M. Reid and myself when on the island in 1930, and a brief description of it appears in an article by him on North Rona (9). Though raised beaches are supposed to be rare on the north coast of Scotland, they are definitely known to exist (8), and there is no reason why there should not be one on Rona.

At Geodha Hacaclaid on the south-west of the island, and about 30 feet above the sea, there is a deposit of cemented fine-grained material which acts as a matrix to pieces of country rock up to an inch in size. The area exposed here is about 100 feet in length, with a breadth of 18 to 24 inches and a height of a like figure. This deposit lies back about 20 feet from the edge of the cliff. The colour of the matrix is orange-yellow with black specks. Samples were taken and analyses made. There is no sign of any organic remains at all in this deposit, and acid tests showed that there was no calcium carbonate present. In order to study the deposit more fully, samples were taken and carefully pulverized, an obviously unsatisfactory method of breaking it up, but the only one found possible, and after screening with a screen of aperture 2 mm. to separate off the very coarse particles, it was submitted to elutriation. Owing to the diversity in the composition of the grains, hence the difference in specific gravity, and the great variety in the size of the grains, there was reason to believe that some of the readings were untrustworthy. The whole was therefore afterwards submitted to screening. The results obtained by the two methods were comparable for the finer grains. The following is the result of an average of several similar readings.

Mechanical Analysis	VCS	CS	MS	FS	s
	24·15	20·53	37·28	7·53	10·45
Diameters > . .	1	0·5	0·25	0·1	0·05
Cumulative . %s	24·15	44·68	81·96	89·49	99·94

The grains were composed of exactly the same minerals as the country rock.

The deposit described at Geodha Hacaclaid is by far the largest I have seen on the island. Smaller ones, however, occur at Heallair, east of Leac na Sgrob, and also in the vicinity of the storm beach. At the moment I am unable to say definitely that these deposits are the remains of a previous marine shore, but my observations tend to make this highly probable.

SUMMARY AND CONCLUDING REMARKS.

The island of North Rona bears, on the whole, a close resemblance in structure to the adjacent mainland, with certain distinct minor differences.

The evidence shows that the island probably came under the influences of the quaternary ice, as was suggested by Geikie.

In conclusion I should like to express my sincere thanks to all those who have helped me in this work, my thanks being especially due to Mr. D. M. Reid, who accompanied me in 1930, who tendered many useful suggestions and helped me with my work both in the field and laboratory ; and also to Mr. Mackie, of Aberdeen, who on both occasions afforded me the passage in his steam trawlers.

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REVIEWS.

Monsters of Primeval Days. By Dr. W. E. Swinton. pp. 38, 24 plates, with Foreword and Descriptive Notes. "Figurehead": London, 1931. Price 2*s*., or paper covers 1*s*.

THIS little book consists of a series of pictorial reconstructions of some of the more striking reptiles and mammals of past ages represented in their probable natural surroundings. The reconstructions are the work of Mr. Vernon Edwards, modeller to the British Museum, and descriptive notes are added by Dr. Swinton for the reptiles and Mr. Hopwood for the mammals. The result is an admirable book of definite educational and artistic value. Additional interest is given by the estimated ages in years of the geological formations in which the animals were found fossil, these being calculated in accordance with the latest views of men of science as to the earth's age.

F. H. A. M.

Catalogue of the Pontian Carnivora of Europe in the Department of Geology, British Museum (Natural History). By Dr. G. E. Pilgrim. pp. vi + 174, with 2 plates and 30 text-figures. London: Printed by order of the Trustees of the British Museum. 1931. Price 15*s*.

THIS memoir is a companion volume to the *Catalogue of the Pontian Bovidae* issued in 1928, and the general arrangement and style of the two books are similar. Although based on the collections in the Museum, species which are not therein represented are included, so that the work serves as a guide to the Pontian Carnivora of all European deposits. The result is a work well worthy of the best traditions of the Natural History Department. The author provides a useful table showing the European distribution of the species described, these being entered under fifteen different localities. He points out, however, that in doing this he runs the risk of erroneous correlations being made, since definite separation of the fauna into zones can only be done in the Black Sea Provinces of Rumania and Ukraine. Nevertheless, there can be no question that the fauna dealt with is a definite unit of homogeneous character and that this is something less than the so-called "Hipparion fauna" of other writers, since the genus *Hipparion* has a wider range not only in North America and Asia, but also in Europe.

The division of the hyaenas into the two genera, *Hyaena* and *Crocuta*, is here made for the first time by a palaeontologist. Since this classification has hitherto only been applied to living species, being based largely on the study of the soft parts, its employment for extinct species may not escape criticism, as it is arguable that the same correlations between soft and skeletal characters need not necessarily hold good for the extinct types and there may be intermediate species with some of the characters of both genera. The possibility of such criticism is admitted by the author, but for practical purposes the palaeontologist must base his classification on the evidence available, recognizing that all taxonomic divisions are to a large extent arbitrary and depend on ignorance of intermediate forms.

The work is provided with an excellent bibliography, and Miss Woodward's figures are of great merit.

F. H. A. M.

OCEANOGRAPHY: ITS SCOPE, PROBLEMS, AND ECONOMIC IMPORTANCE. By HENRY B. BIGELOW. Published by Chapman & Hall, Ltd., London.

IN spite of the fact that the study of oceanography and the recognition of the vital importance of such a study as a branch of economic zoology may be said to owe its inception in the main to the famous voyage of the *Challenger*, no really adequate book on the subject has as yet been written in the English (and perhaps one should add the American) language. The present work makes no attempt to give any account either of the methods that have been adopted for the prosecution of this subject, which as the author points out is still in its infancy, or of the results that have been achieved up to the present time. As the latter part of the title clearly indicates, the book deals with the scope, problems, and economic importance of this great subject and forms part of a report that was submitted to the American National Academy of Sciences, regarding the share that the United States of America might and should play in the advancement of our knowledge. To any one who is engaged in oceanographic work the book will prove both interesting and useful, especially in regard to the various problems that may arise in the course of his work, or further lines of research in which more information is required; in this connection one may perhaps be permitted to express the view that in his conclusion that the investigation of the present-day deep-sea deposits will throw much-needed light on the origin and method of formation of past deposits, such as the Chalk and the algal coals, that grade into the black shales, the author appears to be somewhat unduly optimistic, since it is difficult to see how a study of deep-sea formations will assist us in the elucidation of problems regarding deposits that are almost certainly of shallow-water origin. Much more might have been said regarding those internal oscillations, or "seiches", that have been shown to occur in comparatively small areas, such as coastal bays, but which in all probability equally occur in the larger oceanic basins, and which, where present, must have a profound influence on the fauna. The chapter dealing with the economic importance of oceanography is, or should be, very helpful, since oceanographic research necessitates the fitting out and financing of research ships and thus entails considerable expense; in these days adequate funds can only be provided by Governments or wealthy bodies that for the most part expect to see some financial return for the outlay, and it is as well that the economic importance should be clearly stated.

In conclusion there are several misprints, some of them particularly glaring, as for instance the substitution on at least two occasions of the word " conversation " for " conservation ".

R. B. S. S.

TABLES FOR THE DETERMINATION OF MINERALS BY MEANS OF THEIR PHYSICAL PROPERTIES, OCCURRENCES, AND ASSOCIATES. By E. H. KRAUS and W. F. HUNT. pp. ix + 266. New York and London: McGraw Hill Publishing Co., Ltd., 1930. Price 15*s*.

THIS work is a second edition, with minor alterations and additions, of a volume first published in 1911. Characters easily observed in macroscopic specimens form the basis of classification, under the headings of lustre, colour, streak, and hardness. The choice of such non-essential characters leads to frequent repetition of many of the commoner minerals, only 250 separate species being described in almost as many pages. Tested by such examples as tourmaline, barite, and dolomite, however, these repetitions appear to have been made in such a way as to cover all the variations likely to be encountered in practice, and the only drawback to the size of the tables would appear to be that it necessitates a price somewhat high for the general student. A useful paragraph on characteristics and associates is appended to each description.

F. C. P.

THE KAOLIN MINERALS. By C. S. ROSS and P. F. KERR. United States Geological Survey Professional Paper No. 165E. pp. 151–76. 1931.

IN this paper, which will be of great interest and value to all who have studied the weathering of felspar, the authors give their results of detailed investigations into the mineral nature of what has been somewhat loosely termed " kaolin ". They recognize at least three " kaolin minerals ", nacrite, dickite, and kaolinite-anauxite. They advocate the retention of these names.

Nacrite is very rare, specimens being available from two localities only.

The name " dickite " is given to the mineral found in Anglesey and described by the late Mr. A. B. Dick. It occurs in a few localities in North America. This is the only kaolin mineral to show those beautifully sharp hexagonal plates we were taught to associate with kaolinite and which many of us have sought for vainly in kaolin under the microscope.

"Kaolinite-anauxite" is thought by the authors to form a series with the alumina to silica ratios ranging from 1 : 2 to 1 : 3.

Tables are given showing the similarities and differences between these three minerals. A useful diagnostic feature is that nacrite and dickite are not easily stained and not pleochroic when stained, whereas kaolinite absorbs dye strongly and is then very pleochroic.

Kaolinite loses the greater part of its water at about 450 degrees C.; dickite at about 575 degrees C.; nacrite at about 650 degrees C.

The authors investigated the possibility of muscovite being formed as an intermediate product in the kaolinization of felspar and concluded that this intermediate product is not muscovite but a mineral similar to kaolinite, having one instead of two molecules of combined water.

Nacrite and dickite are regarded as having been formed by hydrothermal or gas-phase (pneumatolytic) processes, and kaolinite they regard as being formed by weathering. They evidently view with suspicion reported cases of pneumatolytic kaolin, including those of Cornwall and Devon. They say that if these originated from pneumatolysis nacrite and dickite, stable at higher temperatures than kaolinite, should be found; but here the authors fail to take into account the possibility of pressure permitting the formation of kaolinite at higher temperatures than 450 degrees C. One authority is quoted in favour of the West of England deposits being formed by weathering, but it would be easy to quote many observers who are convinced they are not formed by weathering.

At the end of the last century it was generally held among English geologists that muscovite is the weathering-product of alkali-felspars and that kaolinite was only formed from felspar by pneumatolysis. The truth regarding kaolinite appears now to be that it is an abundant and normal weathering-product of alkali-felspars in wet tropical countries, but that it also has been formed by pneumatolytic or hydrothermal action.

This paper contains some excellent plates and also the results of X-ray examination of the minerals. It is clear that the authors have been at great pains to obtain pure material for their analyses and they have put all those interested in kaolin under a debt of gratitude by clearing up a lot of confusion.

J. B. S.

China-Clay (Kaolin). An Imperial Institute Report on the Mineral Industry of the British Empire and Foreign Countries. pp. 1–100. H.M. Stationery Office, 1931. Price 1*s.* 6*d.*

THIS is another addition to the useful reports issued by the Imperial Institute on the mineral industry of the British Empire and foreign countries. It is chiefly concerned with the uses and production of kaolin and its occurrence in various countries, but several chemical analyses are given and the volume ends with a list of references to technical literature. The introduction deals briefly with the nature and origin of kaolin. Three theories to explain the conversion of felspar into kaolin are mentioned : (*a*) by igneous emanations ; (*b*) by surface weathering ; (*c*) by bog or moor water ; but they are not discussed at length and the report is confined in this particular to a short statement of various opinions.

It is interesting to note that Messrs. J. M. Coon and E. J. Lewis are quoted as advocating an increased use of the microscope to regulate the quality of the kaolin put on the market.

It is stated that although widely distributed, commercially valuable kaolin-deposits are comparatively few. By far the most important are those of Cornwall and Devon. Other notable occurrences are those of Czechoslovakia, Germany, France, the United States, and Japan.

The sections on the uses of kaolin and the waste products are of exceptional interest. It is probably generally known now that the chief use of kaolin is not in pottery but in paper-manufacture; nevertheless, most readers will be surprised at the long list of uses to which this commodity has been put ; and it is possible that there are others not mentioned, because the reviewer recollects that long ago he heard of inquiries for kaolin from a firm making cattle-food. The strangest use mentioned in this report is as an absorbent of toxins in the alimentary canal, in which rôle it is said to have produced good results in cases of cholera.

A small defect in the production of this report is that the references in the text to footnotes are by letters in type so small as to be almost illegible.

J. B. S.

DALRADIAN GEOLOGY. By J. W. GREGORY, LL.D., D.Sc., F.R.S., Emeritus Professor of Geology in the University of Glasgow. With 4 plates, 16 diagrams, and 2 maps. Methuen & Co. 12*s*. 6*d*.

THIS book gives an account of the Dalradian rocks of the Scottish Highlands from the viewpoint of Professor Gregory, but his interpretation is not likely to be shared by the majority of the workers on this highly interesting rock series.

The book is as a whole well planned, except that Chapter 8 seems to be misplaced, for it is irritating to the reader constantly to have to refer to the end of the book to find the classification that is in use throughout it. The book may perhaps stimulate some workers on these rocks to take stock of their position, and see where evidence requires further strengthening, but beyond that it cannot be said to contribute much to the real problems of Dalradian Geology.

These problems are in the main twofold, (*a*) the order of the succession, (*b*) the structure viewed in the light of (*a*). With regard to the first of these, the present state of our knowledge does not seem to warrant the sweeping generalizations made in this book. There is no doubt something to be said for an eventual simplification in the nomenclature and classification of the Dalradian schists as a whole, and probably this simplified nomenclature will be feasible first in the South-West Highlands; since, however, such a simplification inevitably carries with it a *correlation*, it should be applied even here with the utmost caution at the present day. Its adoption may lead, indeed, to the obscuring of important issues, as seems to have been the case here in dealing with the Cowal country; Clough realized the difficulties in the interpretation of this region, as is manifest in his Cowal Memoir, but Gregory using his simplified classification has merely glossed them over; they are there none the less.

As might be expected from his earlier papers, Gregory has devoted considerable space to an attempt to establish his Lennoxian Series as distinct from the Dalradian; his evidence is very unconvincing, and seems, indeed, largely to be based upon an entire misconception regarding the metamorphic condition of his Loch Lomond Series. It is a great pity that he tries to force this succession upon the Pre-Cambrian rocks of other countries.

Gregory's views upon metamorphism generally are quite incomprehensible, no clue is given in the book to the facts upon which they are based, and they are so completely at variance with the results obtained by many present-day workers at home and abroad that they inspire no confidence. With regard to the second problem, that of structure, Gregory takes far too much in the Highlands at its face value: he has failed to realize that many of the structures shown in his sections (all too much exaggerated in the vertical scale) are merely superficial: they might all be obliterated, and the structural problem of the Dalradians would still remain.

G. L. E.

CORRESPONDENCE.

SOME RECENT CONTRIBUTIONS TO THE PLEISTOCENE SUCCESSION IN ENGLAND.

SIR,—My thanks are due to Mr. J. Reid Moir and to Professor P. G. H. Boswell for correspondence which has appeared in the GEOLOGICAL MAGAZINE of February and March respectively, with reference to some notes published under the above title in January. The following brief replies may be made.

In the first place, perhaps I may remind Mr. Reid Moir that, if he wishes to apply the glacial sequence of the Alps to this country